HANDBOOK
OF THE
GLASS INDUSTRY

A book of reference for the factory engineer, chemist and plant executive

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PREFACE

This book is the first of its kind. It gathers in a single volume data and information hitherto found in scattered sources. It also contains new material, drawn from the notebooks and files of a number of men who have assisted in its compilation. We are happy to present to the glass industry its first handbook, for the use and information of glassmakers, production men, laboratory technicians, executives, and everyone connected with glass manufacturing who desires to become more effective in his work.

Acknowledgment is gratefully made of the cooperation of a number of individuals and firms who have not only made valuable suggestions as to subject matter, but have freely offered their own material for inclusion in this handbook. We refer, particularly, to Mr. R. F. Hatch, Mr. L. I. Bunce, and the other engineers of the Hartford-Empire Company; Mr. W. R. Lester of the Maryland Glass Corporation; the Chemical Rubber Company, who have permitted us to draw from the comprehensive "Handbook of Chemistry and Physics;" The Ingersoll-Rand Company; the Harbison-Walker Refractories Company; and the Buffalo Forge Company. Other contributors are: Laclede-Christy Clay Products Company, Chas. Taylor Sons Company, Findlay Clay Products Company, Simpson Engineering Company, Frazier-Simplex, Inc. Specific reference to the items for which we are indebted to these sources will be referred to, from time to time, in the book.

We hope that the availability of this handbook as a reference manual will make many calculations easier to perform with accuracy, and that better quantitative work of all sorts in the field of Glass Technology and Engineering will be done because these tools are at hand.

Some of the tables have been introduced by remarks explaining how they may be valuable. To many users of the book, these remarks will seem quite unnecessary. They may prove helpful to many to whom these data are presented for the first time.

We are conscious of the fact that not all the material which some technologists find useful has been included. On the other hand, some information has been given which may be used only at rare intervals or never. Criticisms are invited, so that, if other editions follow, improvements may be made.

CONTENTS

Section I

RAW MATERIALS

Raw Materials

RAW materials for glassmaking are either (1) minerals more or less beneficiated in grinding and preparation, or (2) commercial heavy chemicals. Therefore they are never perfectly represented by ideal chemical formulas, because these take no account of impurities. Percentage compositions calculated from chemical formulas cannot be strictly accurate, although they represent close approximations to actual compositions and are often near enough for approximate calculations.

Whenever glass compositions are to be calculated from batches, or batches from glass compositions, it is necessary, for accurate results, to have at hand analyses of the various materials as actually weighed out. This is especially true of the minerals used for the introduction of silica, alumina, and lime; and attention should also be paid to the sources of alkali, which may have taken up more or less moisture in storage, and to borax, which may have lost part of its water.

On the following pages, the principal raw materials used in glassmaking are tabulated under their names and alternative names sometimes applied when purchased, and to each material has been assigned a theoretical formula representing its chemical composition if it were a pure compound. In the column

Chemical Elements in Glasses and Raw Materials

Name	Symbol	At. Wt.	Log
Aluminum	Al	27.0	1.4314
Antimony	Sb	121.8	2.0857
Arsenic	As	74.9	1.8739
Barium	Ba	137.4	2.1380
Boron	B	10.8	1.0334
Cadmium	Cd	112.4	2.0507
Calcium	Ca	40.1	1.6031
Carbon	C	12.0	1.0792
Cerium	Ce	140.1	2.1464
Chlorine	Cl	35.5	1.5502
Chromium	Cr	52.0	1.7160
Cobalt	Co	58.9	1.7701
Copper	Cu	63.6	1.8035
Fluorine	F	19.0	1.2788
Gold	Au	197.2	2.2951
Hydrogen	H	1.0	0.0000
Iron	Fe	55.8	1.7466
Lead	Pb	207.2	2.3164
Lithium	Li	6.9	0.8388
Magnesium	Mg	24.3	1.3856
Manganese	Mn	54.9	1.7396
Neodymium	Nd	144.3	2.1593
Nickel	Ni	58.7	1.7686
Nitrogen	N	14.0	1.1461
Oxygen	O	16.0	1.2041
Phosphorus	P	31.0	1.4914
Potassium	K	39.1	1.5922
Selenium	Se	79.0	1.8976
Silicon	Si	28.1	1.4487
Silver	Ag	107.9	2.0290
Sodium	Na	23.0	1.3617
Sulfur	S	32.1	1.5065
Tin	Sn	118.7	2.0744
Titanium	Ti	47.9	1.6803
Uranium	U	238.1	2.3768
Vanadium	V	50.9	1.7067
Zinc	Zn	65.4	1.8156
Zirconium	Zr	91.2	1.9600

"Oxides Supplied" appear the formulas of the chemical oxides furnished, respectively, by each of these materials. The next column contains the decimal fraction of these oxides present in the pure compounds represented by the formulas. These fractions are only approximations of the actual oxide contents, and the relative purity or analysis of each of the raw materials must be known when accurate calculations are to be made. Finally, the "Reciprocal" column gives numbers which are the reciprocals of the represented decimal fractions. These reciprocals serve to indicate the weights of raw materials required per unit weight of oxides. For example, 1.531 pounds of hydrated alumina will be required to supply one pound Al_2O_3.

PRINCIPAL RAW MATERIALS USED IN GLASSMAKING

Material	Alternative Name	Theoretical Formula	Oxides Supplied	Fraction	Reciprocal*
Alumina	Calcined Alumina	Al_2O_3	Al_2O_3	1.000	1.000
Aluminum Hyd.	Hydrated Alumina	$Al_2O_3 \cdot 3H_2O$	Al_2O_3	0.654	1.531
Aplite (typical	......	.....	Al_2O_3	1.240	4.167
composition)	......	.....	$Na_2(K_2)O$	0.100	...
	......	.....	SiO_2	0.600	...
	......	.....	CaO	0.060	...
Feldspar	Microcline (Composition is of typical commercial spar)	$K_2O \cdot Al_2O_3 \cdot$-	Al_2O_3	0.180	5.556
		$6SiO_2$	$K_2(Na_2)O$	0.130	...
		.....	SiO_2	0.680	...
Nepheline Syenite	......	.....	Al_2O_3	0.250	4.000
(typical com-	......	.....	$Na_2(K_2)O$	0.150	...
position)	......	.....	SiO_2	0.600	...
Kyanite (90%	......	$Al_2O_3 \cdot SiO_2$	Al_2O_3	0.567	1.763
concentrate)	......	.....	SiO_2	0.433	...
Kaolin	China Clay	$Al_2O_3 \cdot 2SiO_2 \cdot$-	Al_2O_3	0.395	2.57
	......	$2H_2O$	SiO_2	0.465	...
Cryolite	Kryolith	Na_3AlF_6	...	...	...
Antimony Oxide	......	Sb_2O_3	Sb_2O_3	1.000	1.000
Arsenious Oxide	White Arsenic	As_2O_3	As_2O_5	1.160	0.860
Barium Carbonate	......	$BaCO_3$	BaO	0.777	1.288
Barium Oxide	Baryta	BaO	BaO	1.000	1.000
Barium Sulfate	Barytes	$BaSO_4$	BaO	0.657	1.523
Boric Acid	Boracic Acid	$B_2O_3 \cdot 3H_2O$	B_2O_3	0.563	1.776
Borax	......	$Na_2O \cdot 2B_2O_3 \cdot$-	B_2O_3	0.365	2.738
	......	$10H_2O$	Na_2O	0.163	6.135
Anhydrous Borax	("Pyrobor")	$Na_2O \cdot 2B_2O_3$	B_2O_3	0.692	1.445
	......	.....	Na_2O	0.308	3.245
Lime, Burnt	Quick Lime	CaO	CaO	1.000	1.000
Lime, Hydrated	Calcium Hydrate	$CaO \cdot H_2O$	CaO	0.757	1.322
Limestone	Calcium Carb.	$CaCO_3$	CaO	0.560	1.786
Calcium Carb.	Whiting	$CaCO_3$	CaO	0.560	1.786
Lime, Dolomitic	Burnt Dolomite	$CaO \cdot MgO$	CaO	0.582	1.720
	......	.....	MgO	0.418	2.390

PRINCIPAL RAW MATERIALS USED IN GLASSMAKING (*Continued*)

Material	Alternative Name	Theoretical Formula	Oxides Supplied	Fraction	Reciprocal*
Dolomite	Raw Limestone (Dolomitic)	$CaO \cdot MgO \cdot 2CO_2$	CaO MgO	0.304 0.218	3.290 4.580
Lime, Hydrated, Dol.	Finishing Lime	$CaO \cdot MgO \cdot 2H_2O$	CaO MgO	0.423 0.304	2.363 3.290
Litharge	Lead Oxide, Yellow	PbO	PbO	1.000	1.000
Red Lead	Minium	Pb_3O_4	PbO	0.977	1.024
Bone Ash	Calcium Phosphate	$3CaO \cdot 2P_2O_5 + x\ CaCO_3$	CaO P_2O_5	0.372 0.628	2.700 1.592
Iron Oxide, Red	Rouge	Fe_2O_3	Fe_2O_3	1.000	1.000
Potassium Hyd.	Caustic Potash	KOH	K_2O	0.838	1.194
Potas. Nitrate	Saltpeter	KNO_3	K_2O	0.465	2.151
Potassium Carb.	Calcined Carbonate of Potash	K_2CO_3	K_2O	0.681	1.469
Glassmaker's Potash	Potassium Carbonate, Hyd.	$K_2CO_3 \cdot 1^1/_2H_2O$	K_2O	0.570	1.754
Sand	Glass Sand, Quartz	SiO_2	SiO_2	1.000	1.000
Soda Ash	Sod. Carb. Coml.	Na_2CO_3	Na_2O	0.585	1.709
Sodium Nitrate	Saltpeter Chili	$NaNO_3$	Na_2O	0.365	2.741
Salt Cake	Sodium Sulfate	Na_2SO_4	Na_2O	0.437	2.290
Sodium Silicofluoride	Sodium Fluosilicate	Na_2SiF_6	...	...	...
Zinc Oxide	......	ZnO	ZnO	1.000	1.000

* This column gives pounds of material required to supply one pound of oxide.

Feldspar Specifications
(Bureau of Standards)

MESH

U. S. Std. Sieve No.	% Remaining on No. 200	Maximum % Remaining on Sieve Designated
230	0.00– 0.35	1.0
200	0.35– 1.00	1.0
170	1.00– 2.50	1.0
140	2.50– 5.00	1.0
120	5.00– 9.00	1.0
100	9.00–14.00	1.0
80	14.00–21.00	1.0
60	21.00–30.00	0.6
40	30.00–42.00	0.3
20	42.00–60.00	None

Example: "20-mesh" feldspar will all pass a No. 20 sieve, and 42–60% of it will be retained on No. 200 sieve.

COMPOSITION

Number	% Silica (SiO_2)
65	64.00–65.99
67	66.00–67.99
69	68.00–69.99
70	70.00–71.99
	% Alumina (Al_2O_3)
15	15.00–15.99
16	16.00–16.99
17	17.00–17.99
18	18.00–18.99
19	19.00–19.99
	% Iron Ox. (Fe_2O_3)
X	Max. 0.15
XX	Max. 0.20
XXX	Above 0.20

Oxides in Glasses and Raw Materials

Name	Formula	Mol. Wt.	Log	Melting Point °F.	Melting Point °C.
Alumina	Al_2O_3	102.0	2.0086	3720	2050
Antimony Oxide	Sb_2O_3	291.5	2.4646	1210	656
Arsenious Oxide	As_2O_3	197.9	2.2965	s. 380	193
Arsenic Oxide	As_2O_5	229.9	2.3615	d. 600	315
Barium Oxide (Baryta)	BaO	153.4	2.1858	3490	1923
Boron Oxide (Bora)	B_2O_3	69.6	1.8426	c. 570	300
Cadmium Oxide	CdO	128.4	2.1086	>2600	>1425
Calcia (Lime)	CaO	56.1	1.7490	4660	2572
Carbon Dioxide	CO_2	44.0	1.6435	−67	−56
Cerium Oxide	CeO_2	172.1	2.2358	3540	1950
Chromium Oxide (Green)	Cr_2O_3	152.0	2.1818	3615	1990
Chromic Anhydride (Red)	CrO_3	100.0	2.0000	d. 570	300
Cobalt Oxide	Co_3O_4	240.8	2.3818		
Copper Oxide (Black)	CuO	79.6	1.9009	d. 1880	1026
Copper Oxide (Red)	Cu_2O	143.1	2.1556	2255	1235
Hydrogen Oxide (Water)	H_2O	18.0	1.2553	32	0
Iron Oxide (Ferric, Red)	Fe_2O_3	159.7	2.2033	d. 2850	1565
Iron Oxide (Ferro-Ferric, Black)	Fe_3O_4	231.5	2.3645	d. 2800	1538
Iron Oxide (Ferrous, Black)	FeO	71.8	1.8561	x.	
Lead Oxide (Litharge, Yellow)	PbO	223.2	2.3487	1630	888
Lead Oxide (Red Lead, Minium)	Pb_3O_4	685.7	2.8361	d. 930	500
Lime (See Calcia)					
Lithia	Li_2O	29.9	1.4757	>3090	>1700
Magnesia	MgO	40.3	1.6053	5070	2800
Manganese Dioxide	MnO_2	86.9	1.9390	d. 995	535
Manganous Oxide	MnO	70.9	1.8506	3000	1650
Neodymium Oxide	Nd_2O_3	336.5	2.5269		
Nickel Oxide (Green)	NiO	74.7	1.8733	ox. 750	400
Nitric Anhydride	N_2O_5	108.0	2.0344	85	30
Phosphorus Pentoxide	P_2O_5	142.0	2.1523	1045	563
Potash	K_2O	94.2	1.9741	x.	
Selenium Dioxide	SeO_2	111.2	2.0492	645	340
Silica	SiO_2	60.1	1.7789	3135	1725
Soda	Na_2O	62.0	1.7924	x.	
Sulfur Dioxide	SO_2	64.1	1.8069	−100	−73
Sulfur Trioxide	SO_3	80.1	1.9036	62	17
Tin Oxide (Stannic, White)	SnO_2	150.7	2.1782	d. 2060	1127
Tin Oxide (Stannous, Black)	SnO	134.7	2.0959	d. red heat	
Titania (Ti. Diox.)	TiO_2	79.9	1.9025	5300	2930
Uranium Trioxide	UO_3	286.1	2.4566	d. red heat	
Water	H_2O	18.0	1.2553	32	0
Zinc Oxide	ZnO	81.4	1.9106	u.p. >3270	>1800
Zirconia	ZrO_2	122.2	2.0871	4890	2700

s. = sublimes.
d. = decomposes or loses oxygen.
c. = approx. soft. temp. of glassy form.
ox. = oxidizes.
x. = encountered only combined.
u.p. = under pressure.

Bulk Density of Raw Materials

The following figures on bulk density of various materials are based upon experimental weighings and they must be taken as approximations. It is obvious that the packing must depend upon a number of factors: the granulation and assortment of grain sizes, the amount of shaking or vibration which the material has undergone, and the degree of dampness which exists. In mixed materials or glass batch, still greater variation can exist, depending upon how well the voids in one material may be filled by fine particles of another material when mixing is complete. The bulk density of a material depends upon the true density of individual particles less voids, which may run as high as 50 per cent. Bulk densities are useful in estimating the proper sizes for storage bins, weighing hoppers, mixing machines, batch cars, etc.

The bulk or apparent density of a material may be estimated experimentally as follows: Transfer 30.0 g. of the material to a dry 100-ml. graduate. Rotate the graduate until the material flows freely, then level the surface of the sample, taking care to avoid jarring. Read the volume.

$$\text{Apparent sp. gr.} \cdot \frac{30}{\text{Vol. (ml.)}}$$

$$\text{Apparent density, lb./cu. ft.} = \text{Apparent sp. gr.} \times 62.4$$

The packing of raw materials may cause variations in bulk density between 10 and 20 per cent.

Bulk Density—Glass Batch Ingredients

(Weights and Volumes)

Material	Type	Screen Through No. 16	Screen On No. 100	Lbs. per Cu. Ft. Loose Poured	Lbs. per Cu. Ft. Vibrated Jarred	Storage Cu. Ft. per Ton (Approx.) *Bulk	Storage Cu. Ft. per Ton (Approx.) Bags
Sand	Pa.	100%	95%	86	99	22	..
Soda Ash	Dense (granular)	100	98	61	74	30	35
Salt Cake	Granular	100	98	85	95	22	..
Limestone	Crushed	100	83	95	108	20	..
Raw Dolomite	Crushed	91	92	87	97	22	..
Burnt Dolomite	Milled	100	2	51	62	35	40
Burnt Lime	Milled	100	2	35	45	50	55
Aplite	Milled	100	74	93	109	20	26
Feldspar	Milled	100	55	80	..	25	34
Neph. Syenite	Milled	100	79	93	104	20	26
Borax	Cryst.	100	94	53	57	36	45
Barytes	Milled	100	0	111	142	16	..
Fluorspar	Milled	100	7	89	114	20	..
Red Lead	...	100	0	..	190	..	..
Lime Batch	...	...	..	80	90	23	..
Cullet	Water-quenched; walnut size and under			95	104	20	..

* Based on the mean of the preceding two values.

Melting Points

Name	Formula	Melting Point °F.	°C.
Aluminum Oxide	Al_2O_3	3720	2050
Aluminum Silicate (Mullite)	$3Al_2O_3 \cdot 2SiO_2$	3290	1810
Barium Carbonate	$BaCO_3$	d. 2640	1450
Barium Nitrate	$Ba(NO_3)_2$	1100	592
Barium Silicate	$BaSiO_3$	2920	1605
Barium Sulfate	$BaSO_4$	2875	1580
Boric Acid	H_3BO_3	d. 365	185
Boron Oxide Cryst.	B_2O_3	c. 910	490
Calcia	CaO	4660	2572
Calcium Carbonate	$CaCO_3$	d. Bright red heat	
Calcium Fluoride	CaF_2	2480	1360
Calcium Nitrate	$Ca(NO_3)_2$	1040	560
Calcium Pyro-Phosphate	$Ca_2P_2O_7$	2245	1230
Tricalcium Phosphate	$Ca_3(PO_4)_2$	3040	1670
Calcium Silicate	$CaSiO_3$	2805	1540
Calcium Sulfate	$CaSO_4$	2640	1450
Chromic Oxide	Cr_2O_3	3615	1990
Copper (Metal)	Cu	1981	1083
Cryolite	Na_3AlF_6	1830	1000
Ferrous Silicate	$FeSiO_3$	2200	1200
Lead (Metal)	Pb	620	327
Lead Metaborate	$Pb(BO_2)_2$	Low red heat	
Lead Oxide (Litharge)	PbO	1630	888
Lead Oxide (Red Lead)	Pb_3O_4	d. 930	500
Lead Silicate	$PbSiO_3$	1410	766
Lithium Carbonate	Li_2CO_3	1145	618
Lithium Nitrate	$LiNO_3$	490	255
Lithium Silicate	Li_2SiO_3	2190	1200
Lithium Sulfate	Li_2SO_4	1580	860
Magnesium Carbonate	$MgCO_3$	d. Low red heat	
Magnesium Oxide	MgO	5070	2800
Magnesium Silicate	$MgSiO_3$	2835	1555
Magnesium Sulfate	$MgSO_4$	2165	1185
Phosphorus Pentoxide	P_2O_5	1045	563
Platinum (Metal)	Pt	3227	1775
Potassium Carbonate	K_2CO_3	1635	891
Potassium Hydroxide	KOH	716	380
Potassium Nitrate	KNO_3	635	334
Potassium Silicate	K_2SiO_3	1790	976
Potassium Sulfate	K_2SO_4	1970	1076
Selenium	Se	Boils 1270	688
Selenium Dioxide	SeO_2	644	340
Silica	SiO_2	3135	1725
Silver (Metal)	Ag	1761	960
Sodium Aluminate	$NaAlO_2$	3000	1650
Sodium Diborate	$Na_2B_4O_7$	1365	741
Sodium Carbonate	Na_2CO_3	1562	851
Sodium Chloride	NaCl	1480	804
		Boils 2575	1413
Sodium Nitrate	$NaNO_3$	587	308
Sodium Silicate	Na_2SiO_3	1990	1089

MELTING POINTS (*Continued*)

Name	Formula	Melting Point	
Sodium Disilicate	$Na_2Si_2O_7$	1605	874
Sodium Sulfate	Na_2SO_4	1624	884
Sulphur	S	Boils 827	444.6
Zinc Oxide	ZnO	u.p. >3270	u.p. >1800
Zinc Silicate	$ZnSiO_3$	2620	1437
Zirconia	ZrO_2	4890	2700
Zirconium Silicate (Zircon)	$ZrSiO_4$	4620	2550

d. = decomposes or loses oxygen. u.p. = under pressure.
c. = approx. soft temp. of glassy form.
Sources: Chemical Rubber Co.'s "Handbook of Chemistry and Physics."
International Critical Tables.

Equivalent Weights of Raw Materials

The following table is intended to facilitate calculations when one raw material is substituted for another, or when batches are calculated from compositions of glasses.

Example: How much soda ash is replaced, when salt cake is put in the batch? Opposite "Salt Cake," in the left-hand, unit-wt. column, is found "Soda Ash," with weight 0.74, to supply an equal amount of Na_2O. The weight of salt cake used, multiplied by 0.74, gives the weight of soda ash replaced.

Material Used, Unit Wt.	Material Replaced	Weight	Oxide Supplied
Soda Ash	Sodium Nitrate	1.61	Na_2O
Sodium Nitrate	Soda Ash	0.62	Na_2O
Soda Ash	Salt Cake	1.35	Na_2O
Salt Cake	Soda Ash	0.74	Na_2O
Soda Ash	Borax	3.62	Na_2O
Borax	Soda Ash	0.27	Na_2O
Hyd. Carb. Potash	Saltpeter	1.21	K_2O
Saltpeter	Hyd. Carb. Potash	0.82	K_2O
Hyd. Carb. Potash	Calcined Carb. Potash	0.87	K_2O
Calcined Carb. Potash	Hyd. Carb. Potash	1.19	K_2O
Feldspar	Sand	0.68	SiO_2
Sand	Feldspar	1.47	SiO_2
Feldspar	Alumina Hydrate	0.27	Al_2O_3
Nepheline Syenite	Feldspar	1.92	Al_2O_3
Aplite	Feldspar	1.62	Al_2O_3
Alumina Hydrate	Feldspar	3.61	Al_2O_3
Limestone	Burnt Lime	0.56	CaO
Burnt Lime	Limestone	1.78	CaO
Dol. Limestone	Burnt Dol. Lime	0.52	$CaO \cdot MgO$
Burnt Dol. Lime	Dol. Limestone	1.93	$CaO \cdot MgO$
Burnt Dol. Lime	Hyd. Dol. Lime	1.33	$CaO \cdot MgO$
Hyd. Dol. Lime	Burnt Dol. Lime	0.75	$CaO \cdot MgO$
Borax	Boric Acid	0.64	B_2O_3
Boric Acid	Borax	1.56	B_2O_3
Borax	Dehydrated Borax	0.52	B_2O_3, Na_2O
Dehydrated Borax	Borax	1.93	B_2O_3, Na_2O

Calculation of Glass Composition from Batch

General Rules

1. Multiply the weight of each raw material by its factor for each oxide furnished to the glass.
2. Add the total weight of oxides. This sum is the weight of glass formed from the batch.
3. Collect and add the weights of each oxide from different sources.
4. The weight of each oxide, divided by the total weight of glass formed, and multiplied by one hundred, gives the per cent of the oxide in the finished glass.
5. Check the calculation by adding these percentages, which should total 100.0 ± 0.1.

This calculation is applied to a typical batch for container glass, below.

In practice, a glass melted from the present batch would contain about 0.5 per cent Al_2O_3, because of alumina derived from the sand, the lime, and the tank blocks.

Errors

1. This calculation is necessarily based on an ideal or theoretical composition for each material. It is therefore inaccurate to the extent

A Batch for Container Glass

Material	Wt.	Factor	Oxide	Wt.
Sand	1000	1.000	SiO_2	1000.0‡
Soda Ash	375	0.585	Na_2O	219.4
Salt Cake	5	0.437	Na_2O	2.2
Borax	35	0.163	Na_2O	5.7
		0.365	B_2O_3	12.8
Feldspar	50	0.680	SiO_2	34.0
		0.180	Al_2O_3	9.0
		0.130	Na_2O	6.5
Dol. Lime	110	0.582	CaO	64.0
		0.418	MgO	46.0
				1399.6

Collected Weights			Comp., %
SiO_2	1034.0	÷ 1399.6* =	73.88‡
Na_2O	233.8†	"	16.71†
B_2O_3	12.8	"	0.91
Al_2O_3	9.0	"	0.64
CaO	64.0	"	4.57
MgO	46.0	"	3.29
Total Glass	1399.6‡		100.00

* Time is often saved by first dividing 100 by the total weight of glass, and multiplying each oxide weight by this quotient.

† Includes, of course, K_2O.

‡ This decimal place is carried for the sake of arithmetical completeness in this illustration. It is scarcely justified by the data or the facts of batch handling and melting.

that the actual compositions differ from the theoretical.

2. No account is taken of the impurities, particularly alumina which occurs in all sands and limestones. More precise estimation of final composition requires analytical knowledge of the raw materials and allowance for such impurities.

3. All commercial glass corrodes the walls of the tank or pot in which it is melted, and thus takes up a small content of alumina. It also dissolves silica from these walls; but since the silica content of the wall material is lower than that of the glass, the result is a slight lowering of silica content from that calculated. The alumina thus introduced cannot be accurately estimated, because it varies with temperature, the character and age of the containing walls, and the nature of the glass.

4. Certain oxides are lost from the glass in small amounts by vaporization. This is notably true of B_2O_3 and, to a lesser extent, of Na_2O and K_2O. The result is that the glass usually contains somewhat less boron oxide and alkali than the calculated values.

5. Some raw material is carried mechanically from the batch during the melting process by the movement of flame gases across the batch and by the vigorous evolution of gas bubbles during melting. In general, lime is the principal oxide thus carried away.

6. Finished glass contains dissolved gases, principally SO_3, CO_2, and H_2O, which cannot be estimated by calculation. Of these, SO_3 becomes important in glasses from batch containing sulfate, and may amount to as much as one per cent of the finished glass. It is also difficult to estimate, except by analytical check, how much arsenic may be retained by the glass.

7. Finally, colorants, decolorizers, oxides of iron, titania, and minor impurities are seldom taken account of in calculations, but may amount to appreciable percentages.

Calculation of Batch from Glass Composition

General Rules

1. Since certain raw materials supply more than one oxide each, and since there are often several sources present for the same oxide, it becomes necessary to start this calculation with the more complex raw materials.

2. Consider that the tabulated analysis or composition of glass in oxides per cent represents 100 lb. of glass, and that each percentage represents a certain number of pounds weight of oxide.

3. Begin with the weight of alumina desired, and multiply this by the reciprocal factor for the aluminous raw material chosen; for example, feldspar. Multiply the weight of feldspar thus obtained by the factor for silica, and subtract this result from the weight of silica required. This difference is the weight of sand necessary. Similarly, multiply the weight of feldspar by its alkali factor.

4. If the glass contains B_2O_3, it is generally assumed that borax will be used as a raw material. Multiply the weight of B_2O_3 by its reciprocal factor, and calculate from the weight of borax thus obtained the weight of Na_2O which it carries.

5. Salt cake is ordinarily introduced as a fixed proportion to the sand present. Estimate and record this weight, and calculate from it the weight of Na_2O which it carries. If niter is also used, perform a similar operation for this material. Collect the weights of Na_2O from feldspar (in these calculations K_2O is assumed to substitute for Na_2O), borax, salt cake, and niter, if any. Add them, and subtract from the weight of soda in the hundred pounds of glass. Multiply the remainder by the reciprocal factor for soda ash from soda, to obtain the quantity of soda ash required.

6. Calculation for the "lime" depends upon the type of raw material selected. If the glass contains magnesia, inspection of the CaO:MgO ratio will indicate whether dolomite or dolomitic lime, or a mixture of dolomitic and high-calcium lime is required. The appropriate reciprocal factors are then applied. But if dolomitic lime is used, calculation from the CaO weight alone provides for the necessary amount of dolomitic lime to carry the magnesia as well.

7. Arsenic and decolorizers are supplied according to the judgment of the glassmaker. Estimates for SO_3 and impurities are, of course, not possible.

This method is illustrated below, by calculating back from the composition found on page 10. We thus arrive at the original batch, and check the former calculation.

Conversion of raw material weights to final weights for batch on 1000-lb.-sand basis is done by multiplying by 1000 divided by sand weight.

In practice, a number like 0.3 or 0.4 (derived from experience with the raw materials and tank) is subtracted from the alumina shown in the analysis, before feldspar is calculated.

Analyses written to hundredths per cent express greater accuracy than the silicate analyst possesses. One decimal place is all that is justified, at least for the major ingredients.

Container Glass Composition

In 100 Lb.:		Deductions	Reciprocal	Lb.	Raw Material	Final Batch
SiO_2	73.88	− 2.42 = 71.46	× 1.00 =	71.46	Sand	1000
Na_2O	16.71	− 1.02 = 15.69	× 1.71 =	26.82	Soda Ash	375
B_2O_3	0.91		× 2.74 =	2.49	Borax	35
Al_2O_3	0.64		× 5.56 =	3.56	Feldspar	50
CaO	4.57		× 1.72 =	7.85	Dol. Lime	110
MgO	3.29	(included in Dolomitic Lime)		0.36	Salt Cake	5

Feldspar	3.56 × 0.680	= 2.42 lb. SiO_2 from Feldspar
Feldspar	3.56 × 0.130	= 0.46 lb. Alk. from Feldspar
Borax	2.49 × 0.163	= 0.41 lb. Alk. from Borax
Sand	71.46 × 0.005	= 0.36 lb. Salt Cake
Salt Cake	0.36 × 0.437	= 0.15 lb. Alk. from Salt Cake

Colorants for Glass

Material	Color Produced Under Oxidation	Color Produced Under Reduction
Cadmium Sulfide	None	Yellow
Cadmium Sulfide, Selenium	None	Ruby (on reheating)
Cobalt Oxide	Blue-violet	Blue-violet
Copper Oxide (bl.)	Greenish blue	Greenish blue
Cuprous Oxide	Greenish blue	Ruby (on reheating)
Cerium Oxide, Titania	Yellow	Yellow
Chromic Oxide	Yellowish green	Emerald-green
Gold	Ruby on reheating	
Iron Oxide	Yellowish green	Bluish green
Manganese Dioxide	Amethyst to purple	None
Neodymium Oxide	Violet	Violet
Nickel Oxide	Violet in K_2O glasses	Same
	Brown in Na_2O glasses	Same
Selenium	Fugitive	Pink
Sulfur	None	Yellow to amber
Uranium	Yellow, with green fluorescence	Green, with fluorescence

Potentials of Oxidizing and Reducing Agents

Oxidizing Agents			Reducing Agents		
Agent	Product	Cal./g.-atom oxygen	Agent	Product	Cal./g.-atom oxygen
N_2O_5	2NO	+14	2Al	Al_2O_3	+133
O_2 (as element)		0	Zn	ZnO	+84
$2CrO_3$	Cr_2O_3	− 3	SnO	SnO_2	+68
CaO_2	CaO	− 4	CO	CO_2	+68
Ag_2O	2Ag	− 7	Fe	FeO	+64
Pb_3O_4	3PbO	−16	2FeO	Fe_2O_3	+63
BaO_2	BaO	−19	H_2	H_2O	+58
SO_3	SO_2	−22	Pb	PbO	+53
$2MnO_2$	Mn_2O_3	−24	C	CO_2	+47
SeO_2	Se	−28	Sb_2O_3	Sb_2O_4	+45
2CuO	Cu_2O	−30	S	SO_2	+35
As_2O_5	As_2O_3	−32	...	...	..

Calculated from International Critical Tables.

The above table shows the relative strengths of oxidizers. Any of the oxidizing agents will oxidize any of the reducing agents, and, of course, vice versa. Heat will be evolved. Exothermic reactions are also to be expected when any agent is heated with a product below its level, on the same side of the table. Heats of decomposition and reaction are given above in terms of kilo-calories per gram-atom of oxygen released or reacting.

Section II

NUMERICAL TABLES

Numerical Tables

Suggestions on the Use of Logarithms

WHENEVER calculations are to be made involving the multiplication or division of numbers having three or more significant figures, the use of logarithms is to be recommended for both speed and accuracy. For such numbers, a slide rule does not yield accurate results, because the setting and the reading for the third significant figure are only estimates. When it is recalled that the slide rule operates on the logarithmic principle, it becomes easy for anyone familiar with its operation to use the logarithms themselves.

To multiply together two or more numbers, add their logarithms, and find in the "log" table the number whose log is the sum.

Example:

$365 \times 46 \times 0.781$:

log 365 is 2.5623

log 46 is 1.6628

log 0.781 is 9.8927 − 10*

* The "characteristic" (at the left of the decimal point) is the number of places in the original number to the left of the decimal point, less one. If the original number is a decimal, the characteristic of its log will be *minus* one more than the number of zeros at the right of the decimal point. It is usually written as some number −10, for convenience in adding or subtracting.

The sum, 14.1178 − 10, or 4.1178, is the log of the product. In the table, 0.1173 appears as the log of 1310; 0.1206 is the log of 1320; 0.1178 − 0.1173 = 0.0005; the nearest "proportional part" shown is 6, corresponding to 2 in the fourth place; our product is nearly *13,120.* More exactly, it is found by taking

$$10 \times \frac{5}{(1206-1173)} = 1.5$$ as the correction, making the product *13,115.*

Division is performed by subtracting the log of the divisor from the log of the dividend. Here, operations are simplified by adding the "co-log" of each divisor. The co-log, or log of reciprocal, is written by mentally subtracting the log of the number from zero, which is the log of 1. In practice, the log of 1 is written "10.0000 − 10."

Example, to solve $\frac{298 \times 0.36}{0.207 \times 0.53}$:

log 298 is 2.4742	2.4742
log 0.36 is 9.5563 − 10	−1.5563
log 0.207 is 9.3160 − 10 co-log	0.6840
log 0.053 is 8.7243 − 10 co-log	1.2757
sum	3.9902

The answer is the number whose log is 3.9902, which is 9782.

(*Continued on page 20*)

Common Logarithms of Numbers*

No.	0	1	2	3	4	5	6	7	8	9	Proportional Parts								
											1	2	3	4	5	6	7	8	9
10	0000	0043	0086	0128	0170	0212	0253	0294	0334	0374	4	8	12	17	21	25	29	33	37
11	0414	0453	0492	0531	0569	0607	0645	0682	0719	0755	4	8	11	15	19	23	26	30	34
12	0792	0828	0864	0899	0934	0969	1004	1038	1072	1106	3	7	10	14	17	21	24	28	31
13	1139	1173	1206	1239	1271	1303	1335	1367	1399	1430	3	6	10	13	16	19	23	26	29
14	1461	1492	1523	1553	1584	1614	1644	1673	1703	1732	3	6	9	12	15	18	21	24	27
15	1761	1790	1818	1847	1875	1903	1931	1959	1987	2014	3	6	8	11	14	17	20	22	25
16	2041	2068	2095	2122	2148	2175	2201	2227	2253	2279	3	5	8	11	13	16	18	21	24
17	2304	2330	2355	2380	2405	2430	2455	2480	2504	2529	2	5	7	10	12	15	17	20	22
18	2553	2577	2601	2625	2648	2672	2695	2718	2742	2765	2	5	7	9	12	14	16	19	21
19	2788	2810	2833	2856	2878	2900	2923	2945	2967	2989	2	4	7	9	11	13	16	18	20
20	3010	3032	3054	3075	3096	3118	3139	3160	3181	3201	2	4	6	8	11	13	15	17	19
21	3222	3243	3263	3284	3304	3324	3345	3365	3385	3404	2	4	6	8	10	12	14	16	18
22	3424	3444	3464	3483	3502	3522	3541	3560	3579	3598	2	4	6	8	10	12	14	15	17
23	3617	3636	3655	3674	3692	3711	3729	3747	3766	3784	2	4	6	7	9	11	13	15	17
24	3802	3820	3838	3856	3874	3892	3909	3927	3945	3962	2	4	5	7	9	11	12	14	16
25	3979	3997	4014	4031	4048	4065	4082	4099	4116	4133	2	3	5	7	9	10	12	14	15
26	4150	4166	4183	4200	4216	4232	4249	4265	4281	4298	2	3	5	7	8	10	11	13	15
27	4314	4330	4346	4362	4378	4393	4409	4425	4440	4456	2	3	5	6	8	9	11	13	14
28	4472	4487	4502	4518	4533	4548	4564	4579	4594	4609	2	3	5	6	8	9	11	12	14
29	4624	4639	4654	4669	4683	4698	4713	4728	4742	4757	1	3	4	6	7	9	10	12	13
30	4771	4786	4800	4814	4829	4843	4857	4871	4886	4900	1	3	4	6	7	9	10	11	13
31	4914	4928	4942	4955	4969	4983	4997	5011	5024	5038	1	3	4	6	7	8	10	11	12
32	5051	5065	5079	5092	5105	5119	5132	5145	5159	5172	1	3	4	5	7	8	9	11	12
33	5185	5198	5211	5224	5237	5250	5263	5276	5289	5302	1	3	4	5	6	8	9	10	12
34	5315	5328	5340	5353	5366	5378	5391	5403	5416	5428	1	3	4	5	6	8	9	10	11
35	5441	5453	5465	5478	5490	5502	5514	5527	5539	5551	1	2	4	5	6	7	9	10	11
36	5563	5575	5587	5599	5611	5623	5635	5647	5658	5670	1	2	4	5	6	7	8	10	11
37	5682	5694	5705	5717	5729	5740	5752	5763	5775	5786	1	2	3	5	6	7	8	9	10
38	5798	5809	5821	5832	5843	5855	5866	5877	5888	5899	1	2	3	5	6	7	8	9	10
39	5911	5922	5933	5944	5955	5966	5977	5988	5999	6010	1	2	3	4	5	7	8	9	10
40	6021	6031	6042	6053	6064	6075	6085	6096	6107	6117	1	2	3	4	5	6	8	9	10
41	6128	6138	6149	6160	6170	6180	6191	6201	6212	6222	1	2	3	4	5	6	7	8	9
42	6232	6243	6253	6263	6274	6284	6294	6304	6314	6325	1	2	3	4	5	6	7	8	9
43	6335	6345	6355	6365	6375	6385	6395	6405	6415	6425	1	2	3	4	5	6	7	8	9
44	6435	6444	6454	6464	6474	6484	6493	6503	6513	6522	1	2	3	4	5	6	7	8	9
45	6532	6542	6551	6561	6571	6580	6590	6599	6609	6618	1	2	3	4	5	6	7	8	9
46	6628	6637	6646	6656	6665	6675	6684	6693	6702	6712	1	2	3	4	5	6	7	7	8
47	6721	6730	6739	6749	6758	6767	6776	6785	6794	6803	1	2	3	4	5	5	6	7	8
48	6812	6821	6830	6839	6848	6857	6866	6875	6884	6893	1	2	3	4	4	5	6	7	8
49	6902	6911	6920	6928	6937	6946	6955	6964	6972	6981	1	2	3	4	4	5	6	7	8
50	6990	6998	7007	7016	7024	7033	7042	7050	7059	7067	1	2	3	3	4	5	6	7	8
51	7076	7084	7093	7101	7110	7118	7126	7135	7143	7152	1	2	3	3	4	5	6	7	8
52	7160	7168	7177	7185	7193	7202	7210	7218	7226	7235	1	2	2	3	4	5	6	7	7
53	7243	7251	7259	7267	7275	7284	7292	7300	7308	7316	1	2	2	3	4	5	6	6	7
54	7324	7332	7340	7348	7356	7364	7372	7380	7388	7396	1	2	2	3	4	5	6	6	7

* This table gives the mantissas of numbers with the decimal points omitted. Characteristics are determined by inspection from the numbers.

Common Logarithms of Numbers* (*Continued*)

No.	0	1	2	3	4	5	6	7	8	9	Proportional Parts 1	2	3	4	5	6	7	8	9
55	7404	7412	7419	7427	7435	7443	7451	7459	7466	7474	1	2	2	3	4	5	5	6	7
56	7482	7490	7497	7505	7513	7520	7528	7536	7543	7551	1	2	2	3	4	5	5	6	7
57	7559	7566	7574	7582	7589	7597	7604	7612	7619	7627	1	2	2	3	4	5	5	6	7
58	7634	7642	7649	7657	7664	7672	7679	7686	7694	7701	1	1	2	3	4	4	5	6	7
59	7709	7716	7723	7731	7738	7745	7752	7760	7767	7774	1	1	2	3	4	4	5	6	7
60	7782	7789	7796	7803	7810	7818	7825	7832	7839	7846	1	1	2	3	4	4	5	6	6
61	7853	7860	7868	7875	7882	7889	7896	7903	7910	7917	1	1	2	3	4	4	5	6	6
62	7924	7931	7938	7945	7952	7959	7966	7973	7980	7987	1	1	2	3	4	4	5	6	6
63	7993	8000	8007	8014	8021	8028	8035	8041	8048	8055	1	1	2	3	3	4	5	5	6
64	8062	8069	8075	8082	8089	8096	8102	8109	8116	8122	1	1	2	3	3	4	5	5	6
65	8129	8136	8142	8149	8156	8162	8169	8176	8182	8189	1	1	2	3	3	4	4	5	6
66	8195	8202	8209	8215	8222	8228	8235	8241	8248	8254	1	1	2	3	3	4	4	5	6
67	8261	8267	8274	8280	8287	8293	8299	8306	8312	8319	1	1	2	3	3	4	4	5	6
68	8325	8331	8338	8344	8351	8357	8363	8370	8376	8382	1	1	2	3	3	4	4	5	6
69	8388	8395	8401	8407	8414	8420	8426	8432	8439	8445	1	1	2	2	3	4	4	5	6
70	8451	8457	8463	8470	8476	8482	8488	8494	8500	8506	1	1	2	2	3	4	4	5	6
71	8513	8519	8525	8531	8537	8543	8549	8555	8561	8567	1	1	2	2	3	4	4	5	5
72	8573	8579	8585	8591	8597	8603	8609	8615	8621	8627	1	1	2	2	3	4	4	5	5
73	8633	8639	8645	8651	8657	8663	8669	8675	8681	8686	1	1	2	2	3	4	4	5	5
74	8692	8698	8704	8710	8716	8722	8727	8733	8739	8745	1	1	2	2	3	4	4	5	5
75	8751	8756	8762	8768	8774	8779	8785	8791	8797	8802	1	1	2	2	3	3	4	5	5
76	8808	8814	8820	8825	8831	8837	8842	8848	8854	8859	1	1	2	2	3	3	4	5	5
77	8865	8871	8876	8882	8887	8893	8899	8904	8910	8915	1	1	2	2	3	3	4	4	5
78	8921	8927	8932	8938	8943	8949	8954	8960	8965	8971	1	1	2	2	3	3	4	4	5
79	8976	8982	8987	8993	8998	9004	9009	9015	9020	9025	1	1	2	2	3	3	4	4	5
80	9031	9036	9042	9047	9053	9058	9063	9069	9074	9079	1	1	2	2	3	3	4	4	5
81	9085	9090	9096	9101	9106	9112	9117	9122	9128	9133	1	1	2	2	3	3	4	4	5
82	9138	9143	9149	9154	9159	9165	9170	9175	9180	9186	1	1	2	2	3	3	4	4	5
83	9191	9196	9201	9206	9212	9217	9222	9227	9232	9238	1	1	2	2	3	3	4	4	5
84	9243	9248	9253	9258	9263	9269	9274	9279	9284	9289	1	1	2	2	3	3	4	4	5
85	9294	9299	9304	9309	9315	9320	9325	9330	9335	9340	1	1	2	2	3	3	4	4	5
86	9345	9350	9355	9360	9365	9370	9375	9380	9385	9390	1	1	2	2	3	3	4	4	5
87	9395	9400	9405	9410	9415	9420	9425	9430	9435	9440	0	1	1	2	2	3	3	4	4
88	9445	9450	9455	9460	9465	9469	9474	9479	9484	9489	0	1	1	2	2	3	3	4	4
89	9494	9499	9504	9509	9513	9518	9523	9528	9533	9538	0	1	1	2	2	3	3	4	4
90	9542	9547	9552	9557	9562	9566	9571	9576	9581	9586	0	1	1	2	2	3	3	4	4
91	9590	9595	9600	9605	9609	9614	9619	9624	9628	9633	0	1	1	2	2	3	3	4	4
92	9638	9643	9647	9652	9657	9661	9666	9671	9675	9680	0	1	1	2	2	3	3	4	4
93	9685	9689	9694	9699	9703	9708	9713	9717	9722	9727	0	1	1	2	2	3	3	4	4
94	9731	9736	9741	9745	9750	9754	9759	9763	9768	9773	0	1	1	2	2	3	3	4	4
95	9777	9782	9786	9791	9795	9800	9805	9809	9814	9818	0	1	1	2	2	3	3	4	4
96	9823	9827	9832	9836	9841	9845	9850	9854	9859	9863	0	1	1	2	2	3	3	4	4
97	9868	9872	9877	9881	9886	9890	9894	9899	9903	9908	0	1	1	2	2	3	3	4	4
98	9912	9917	9921	9926	9930	9934	9939	9943	9948	9952	0	1	1	2	2	3	3	4	4
99	9956	9961	9965	9969	9974	9978	9983	9987	9991	9996	0	1	1	2	2	3	3	3	4

* This table gives the mantissas of numbers with the decimal points omitted. Characteristics are determined by inspection from the numbers.

(*Continued from page 17*)

Powers and roots of numbers are found by multiplying or dividing, respectively, by the exponents involved: $\log (298)^2 = 2 \log 298 = 4.9484$, which is the log of $88{,}800 = (298)^2$; with an error of 4 in the fifth significant figure, due to the limitations of a four-place table.

Squares and Square Roots

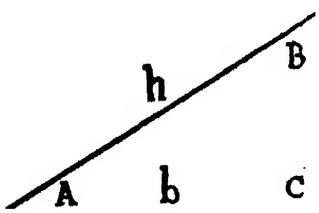
The table which follows is presented as a help in the calculation of flow of gases and in the utilization of formulas. This table is condensed from the usual form, but values for numbers not given can be estimated by interpolation very closely.

n	n^2	$\sqrt{n}$	n	n^2	$\sqrt{n}$	n	n^2	$\sqrt{n}$
1	1	1.0000	44	1,936	6.6333	87	7,569	9.3274
2	4	1.4142	45	2,025	6.7082	88	7,744	9.3808
3	9	1.7321	46	2,116	6.7823	89	7,921	9.4340
4	16	2.0000	47	2,209	6.8557	90	8,100	9.4868
5	25	2.2361	48	2,304	6.9282	91	8,281	9.5394
6	36	2.4495	49	2,401	7.0000	92	8,464	9.5917
7	49	2.6458	50	2,500	7.0711	93	8,649	9.6437
8	64	2.8284	51	2,601	7.1414	94	8,836	9.6954
9	81	3.0000	52	2,704	7.2111	95	9,025	9.7468
10	100	3.1623	53	2,809	7.2801	96	9,216	9.7980
11	121	3.3166	54	2,916	7.3485	97	9,409	9.8489
12	144	3.4641	55	3,025	7.4162	98	9,604	9.8995
13	169	3.6056	56	3,136	7.4833	99	9,801	9.9499
14	196	3.7417	57	3,249	7.5499	100	10,000	10.000
15	225	3.8730	58	3,364	7.6158	110	12,100	10.488
16	256	4.0000	59	3,481	7.6811	120	14,400	10.954
17	289	4.1231	60	3,600	7.7460	130	16,900	11.402
18	324	4.2426	61	3,721	7.8103	140	19,600	11.832
19	361	4.3589	62	3,844	7.8740	150	22,500	12.247
20	400	4.4721	63	3,969	7.9373	160	25,600	12.649
21	441	4.5826	64	4,096	8.0000	170	28,900	13.038
22	484	4.6904	65	4,225	8.0623	180	32,400	13.416
23	529	4.7958	66	4,356	8.1240	190	36,100	13.784
24	576	4.8990	67	4,489	8.1854	200	40,000	14.142
25	625	5.0000	68	4,624	8.2462	210	44,100	14.491
26	676	5.0990	69	4,761	8.3066	220	48,400	14.832
27	729	5.1962	70	4,900	8.3666	230	52,900	15.166
28	784	5.2915	71	5,041	8.4262	240	57,600	15.492
29	841	5.3852	72	5,184	8.4853	250	62,500	15.811
30	900	5.4772	73	5,329	8.5440	260	67,600	16.125
31	961	5.5678	74	5,476	8.6023	270	72,900	16.432
32	1,024	5.6569	75	5,625	8.6603	280	78,400	16.733
33	1,089	5.7446	76	5,776	8.7178	290	84,100	17.029
34	1,156	5.8310	77	5,929	8.7750	300	90,000	17.321
35	1,225	5.9161	78	6,084	8.8318	310	96,100	17.607
36	1,296	6.0000	79	6,241	8.8882	320	102,400	17.889
37	1,369	6.0828	80	6,400	8.9443	330	108,900	18.166
38	1,444	6.1644	81	6,561	9.0000	340	115,600	18.439
39	1,521	6.2450	82	6,724	9.0554	350	122,500	18.708
40	1,600	6.3246	83	6,889	9.1104	360	129,600	18.974
41	1,681	6.4031	84	7,056	9.1652	370	136,900	19.235
42	1,764	6.4808	85	7,225	9.2195	380	144,400	19.494
43	1,849	6.5574	86	7,396	9.2736	390	152,100	19.748

n	n^2	$\sqrt{n}$	n	n^2	$\sqrt{n}$	n	n^2	$\sqrt{n}$
400	160,000	20.000	610	372,100	24.698	810	656,100	28.461
410	168,100	20.248	620	384,400	24.900	820	672,400	28.636
420	176,400	20.494	630	396,900	25.100	830	688,900	28.810
430	184,900	20.736	640	409,600	25.298	840	705,600	28.983
440	193,600	20.976	650	422,500	25.495	850	722,500	29.155
450	202,500	21.213	660	435,600	25.690	860	739,600	29.326
460	211,600	21.448	670	448,900	25.884	870	756,900	29.496
470	220,900	21.679	680	462,400	26.077	880	774,400	29.665
480	230,400	21.909	690	476,100	26.268	890	792,100	29.833
490	240,100	22.136	700	490,000	26.485	900	810,000	30.000
500	250,000	22.361	710	504,100	26.646	910	828,100	30.166
510	260,100	22.583	720	518,400	26.833	920	846,400	30.332
520	270,400	22.804	730	532,900	27.019	930	864,900	30.496
530	280,900	23.022	740	547,600	27.203	940	883,600	30.659
540	291,600	23.238	750	562,500	27.386	950	902,500	30.822
550	302,500	23.452	760	577,600	27.568	960	921,600	30.984
560	313,600	23.664	770	592,900	27.749	970	940,900	31.145
570	324,900	23.875	780	608,400	27.928	980	960,400	31.305
580	336,400	24.083	790	624,100	28.107	990	980,100	31.464
590	348,100	24.290	800	640,000	28.284	1,000	1,000,000	31.623
600	360,000	24.495	...	.....	.....	...	.....	.....

Trigonometry

The principal functions of angles used in engineering calculations are the sine (sin), cosine (cos), tangent (tan), and cotangent (cot). In a right triangle, these are related to the sides as shown below. In the triangle shown, C is a right angle, h is the hypotenuse, side a is opposite angle A, and side b opposite angle B.



$$\text{Sin } A = \frac{a}{h}, \quad \cos A = \frac{b}{h},$$

$$\tan A = \frac{a}{b}, \quad \cot A = \frac{b}{a}.$$

The functions of angles are related to each other as follows:

$$\frac{\sin x}{\cos x} = \tan x. \qquad \frac{\cos x}{\sin x} = \cot x.$$

$$\tan x = \frac{1}{\cot x}. \qquad \cot x = \frac{1}{\tan x}.$$

$\text{Sin } x = \cos(90° - x).$

$\text{Cos } x = \sin(90° - x).$

$\text{Tan } x = \cot(90° - x).$

$\text{Cot } x = \tan(90° - x).$

$\text{Sin } x = \sin(180° - x).$

$\text{Cos } x = -\cos(180° - x).$

$\text{Tan } x = -\tan(180° - x).$

$\text{Cot } x = -\cot(180° - x).$

Natural Trigonometric Functions for Whole Degrees

Note: For Angles Greater than 45°, Read *Up* from Names of Functions at Bottom.

Deg.	Sin	Cos	Tan	Cot	Deg.
0	0.0000	1.0000	0.0000	∞	90
1	0.0175	0.9998	0.0175	57.29	89
2	0.0349	0.9994	0.0349	28.64	88
3	0.0523	0.9986	0.0524	19.08	87
4	0.0698	0.9976	0.0699	14.30	86
5	0.0872	0.9962	0.0875	11.43	85
6	0.1045	0.9945	0.1051	9.514	84
7	0.1219	0.9925	0.1228	8.144	83
8	0.1392	0.9903	0.1405	7.115	82
9	0.1564	0.9877	0.1584	6.314	81
10	0.1736	0.9848	0.1763	5.671	80
11	0.1908	0.9816	0.1944	5.145	79
12	0.2079	0.9781	0.2126	4.705	78
13	0.2250	0.9744	0.2309	4.331	77
14	0.2419	0.9703	0.2493	4.011	76
15	0.2588	0.9659	0.2679	3.732	75
16	0.2756	0.9613	0.2867	3.487	74
17	0.2924	0.9563	0.3057	3.271	73
18	0.3090	0.9511	0.3249	3.078	72
19	0.3256	0.9455	0.3443	2.904	71
20	0.3420	0.9397	0.3640	2.747	70
21	0.3584	0.9336	0.3839	2.605	69
22	0.3746	0.9272	0.4040	2.475	68
23	0.3907	0.9205	0.4245	2.356	67
24	0.4067	0.9135	0.4452	2.246	66
25	0.4226	0.9063	0.4663	2.145	65
26	0.4384	0.8988	0.4877	2.050	64
27	0.4540	0.8910	0.5095	1.963	63
28	0.4695	0.8829	0.5317	1.881	62
29	0.4848	0.8746	0.5543	1.804	61
30	0.5000	0.8660	0.5774	1.732	60
31	0.5150	0.8572	0.6009	1.664	59
32	0.5299	0.8480	0.6249	1.600	58
33	0.5446	0.8387	0.6494	1.540	57
34	0.5592	0.8290	0.6745	1.483	56
35	0.5736	0.8192	0.7002	1.428	55
36	0.5878	0.8090	0.7265	1.376	54
37	0.6018	0.7986	0.7536	1.327	53
38	0.6157	0.7880	0.7813	1.280	52
39	0.6293	0.7771	0.8098	1.235	51
40	0.6428	0.7660	0.8391	1.192	50
41	0.6561	0.7547	0.8693	1.150	49
42	0.6691	0.7431	0.9004	1.111	48
43	0.6820	0.7314	0.9325	1.072	47
44	0.6947	0.7193	0.9657	1.036	46
45	0.7071	0.7071	1.000	1.000	45
	Cos	Sin	Cot	Tan	

Areas of Circles by Sixty-Fourths, from 1/64 to 4 Inches

Formula: $0.7854 \times D_2 = Area$

Diameter	Decimal	Area	Diameter	Decimal	Area	Diameter	Decimal	Area
1/64	0.01562	0.00019	53/64	0.82812	0.53862	1 5/8	1.62500	2.0739
1/32	0.03125	0.00077	27/32	0.84375	0.55914	1 41/64	1.64062	2.1140
3/64	0.04687	0.00173	55/64	0.85937	0.58004	1 21/32	1.65625	2.1545
1/16	0.06250	0.00307	7/8	0.87500	0.60132	1 43/64	1.67187	2.1953
5/64	0.07812	0.00479	57/64	0.89062	0.62299	1 11/16	1.68750	2.2365
3/32	0.09375	0.00690	29/32	0.90625	0.64504	1 45/64	1.70312	2.2782
7/64	0.10937	0.00940	59/64	0.92187	0.66747	1 23/32	1.71875	2.3201
1/8	0.12500	0.01227	15/16	0.93750	0.69029	1 47/64	1.73437	2.3625
9/64	0.14062	0.01553	61/64	0.95312	0.71349	1 3/4	1.75000	2.4053
5/32	0.15625	0.01917	31/32	0.96875	0.73708	1 49/64	1.76562	2.4484
11/64	0.17187	0.02320	63/64	0.98437	0.76105	1 25/32	1.78125	2.4920
3/16	0.18750	0.02761	1	1.00000	0.78540	1 51/64	1.79687	2.5359
13/64	0.20312	0.03241	1	1.00000	0.7854	1 13/16	1.81250	2.5802
7/32	0.21875	0.03758	1 1/64	1.01562	0.8101	1 53/64	1.82812	2.6248
15/64	0.23437	0.04314	1 1/32	1.03125	0.8353	1 27/32	1.84375	2.6699
1/4	0.25000	0.04909	1 3/64	1.04687	0.8608	1 55/64	1.85937	2.7153
17/64	0.26562	0.05542	1 1/16	1.06250	0.8866	1 7/8	1.87500	2.7612
9/32	0.28125	0.06213	1 5/64	1.07812	0.9129	1 57/64	1.89062	2.8074
19/64	0.29687	0.06922	1 3/32	1.09375	0.9396	1 29/32	1.90625	2.8540
5/16	0.31250	0.07670	1 7/64	1.10937	0.9666	1 59/64	1.92187	2.9009
21/64	0.32812	0.08456	1 1/8	1.12500	0.9940	1 15/16	1.93750	2.9483
11/32	0.34375	0.09281	1 9/64	1.14062	1.0218	1 61/64	1.95312	2.9961
23/64	0.35937	0.10143	1 5/32	1.15625	1.0500	1 31/32	1.96875	3.0442
3/8	0.37500	0.11045	1 11/64	1.17187	1.0786	1 63/64	1.98437	3.0927
25/64	0.39062	0.11984	1 3/16	1.18750	1.1075	2	2.00000	3.1416
13/32	0.40625	0.12962	1 13/64	1.20312	1.1369	2 1/64	2.01562	3.1909
27/64	0.42187	0.13978	1 7/32	1.21875	1.1666	2 1/32	2.03125	3.2405
7/16	0.43750	0.15033	1 15/64	1.23437	1.1967	2 3/64	2.04687	3.2906
29/64	0.45212	0.16126	1 1/4	1.25000	1.2272	2 1/16	2.06250	3.3410
15/32	0.46875	0.17257	1 17/64	1.26562	1.2581	2 5/64	2.07812	3.3918
31/64	0.48437	0.18427	1 9/32	1.28125	1.2893	2 3/32	2.09375	3.4430
1/2	0.50000	0.19635	1 19/64	1.29687	1.3209	2 7/64	2.10937	3.4946
33/64	0.51562	0.20881	1 5/16	1.31250	1.3530	2 1/8	2.12500	3.5466
17/32	0.53125	0.22166	1 21/64	1.32812	1.3854	2 9/64	2.14062	3.5989
35/64	0.54687	0.23489	1 11/32	1.34375	1.4182	2 5/32	2.15625	3.6516
9/16	0.56250	0.24850	1 23/64	1.35937	1.4513	2 11/64	2.17187	3.7048
37/64	0.57812	0.26250	1 3/8	1.37500	1.4849	2 3/16	2.18750	3.7583
19/32	0.59375	0.27688	1 25/64	1.39062	1.5188	2 13/64	2.20312	3.8121
39/64	0.60937	0.29165	1 13/32	1.40625	1.5532	2 7/32	2.21875	3.8664
5/8	0.62500	0.30680	1 27/64	1.42187	1.5879	2 15/64	2.23437	3.9210
41/64	0.64062	0.32233	1 7/16	1.43750	1.6229	2 1/4	2.25000	3.9761
21/32	0.65625	0.33824	1 29/64	1.45312	1.6584	2 17/64	2.26562	4.0315
43/64	0.67187	0.35454	1 15/32	1.46875	1.6943	2 9/32	2.28125	4.0873
11/16	0.68750	0.37122	1 31/64	1.48437	1.7305	2 19/64	2.29687	4.1435
45/64	0.70312	0.38829	1 1/2	1.50000	1.7671	2 5/16	2.31250	4.2000
23/32	0.71875	0.40574	1 33/64	1.51562	1.8041	2 21/64	2.32812	4.2570
47/64	0.73437	0.42357	1 17/32	1.53125	1.8415	2 11/32	2.34375	4.3143
3/4	0.75000	0.44179	1 35/64	1.54687	1.8793	2 23/64	2.35937	4.3720
49/64	0.76562	0.46039	1 9/16	1.56250	1.9175	2 3/8	2.37500	4.4301
25/32	0.78125	0.47937	1 37/64	1.57812	1.9560	2 25/64	2.39062	4.4886
51/64	0.79687	0.49874	1 19/32	1.59375	1.9949	2 13/32	2.40625	4.5475
13/16	0.81250	0.51849	1 39/64	1.60937	2.0343	2 27/64	2.42187	4.6067

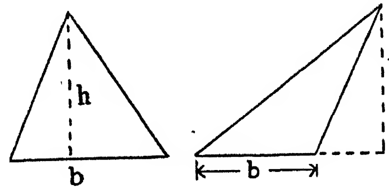
(*Continued on page 24*)

(*Continued from page 23*)

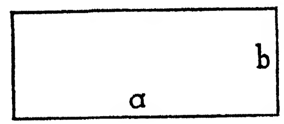
Diameter	Decimal	Area	Diameter	Decimal	Area	Diameter	Decimal	Area
2 7/16	2.43750	4.6664	2 31/32	2.96875	6.9221	3 1/2	3.50000	9.6211
2 29/64	2.45312	4.7264	2 63/64	2.98437	6.9951	3 33/64	3.51562	9.7072
2 15/32	2.46875	4.7868	3	3.00000	7.0686	3 17/32	3.53125	9.7937
2 31/64	2.48437	4.8476	3 1/64	3.01562	7.1424	3 35/64	3.54687	9.8806
2 1/2	2.50000	4.9087	3 1/32	3.03125	7.2166	3 9/16	3.56250	9.9678
2 33/64	2.51562	4.9703	3 3/64	3.04687	7.2912	3 37/64	3.57812	10.0555
2 17/32	2.53125	5.0322	3 1/16	3.06250	7.3662	3 19/32	3.59375	10.1435
2 35/64	2.54687	5.0945	3 5/64	3.07812	7.4415	3 39/64	3.60937	10.2319
2 9/16	2.56250	5.1572	3 3/32	3.09375	7.5173	3 5/8	3.62500	10.3207
2 37/64	2.57812	5.2203	3 7/64	3.10937	7.5934	3 41/64	3.64062	10.4098
2 19/32	2.59375	5.2838	3 1/8	3.12500	7.6699	3 21/32	3.65625	10.4994
2 39/64	2.60937	5.3476	3 9/64	3.14062	7.7468	3 43/64	3.67187	10.5893
2 5/8	2.62500	5.4119	3 5/32	3.15625	7.8241	3 11/16	3.68750	10.6796
2 41/64	2.64062	5.4765	3 11/64	3.17187	7.9017	3 45/64	3.70312	10.7703
2 21/32	2.65625	5.5415	3 3/16	3.18750	7.9798	3 23/32	3.71875	10.8614
2 43/64	2.67187	5.6069	3 13/64	3.20312	8.0582	3 47/64	3.73437	10.9528
2 11/16	2.68750	5.6727	3 7/32	3.21875	8.1370	3 3/4	3.75000	11.0447
2 45/64	2.70312	5.7388	3 15/64	3.23437	8.2162	3 49/64	3.76562	11.1369
2 23/32	2.71875	5.8053	3 1/4	3.25000	8.2958	3 25/32	3.78125	11.2295
2 47/64	2.73437	5.8723	3 17/64	3.26562	8.3757	3 51/64	3.79687	11.3225
2 3/4	2.75000	5.9396	3 9/32	3.28125	8.4561	3 13/16	3.81250	11.4159
2 49/64	2.76562	6.0073	3 19/64	3.29687	8.5290	3 53/64	3.82812	11.5097
2 25/32	2.78125	6.0753	3 5/16	3.31250	8.6179	3 27/32	3.84375	11.6038
2 55/64	2.79687	6.1438	3 21/64	3.32812	8.6994	3 55/64	3.85937	11.6984
2 13/16	2.81250	6.2126	3 11/32	3.34375	8.7813	3 7/8	3.87500	11.7933
2 53/64	2.82812	6.2818	3 23/64	3.35937	8.8636	3 57/64	3.89062	11.8886
2 27/32	2.84375	6.3514	3/8	3.37500	8.9462	3 29/32	3.90625	11.9843
2 55/64	2.85937	6.4214	3 25/64	3.39062	9.0292	3 59/64	3.92187	12.0803
2 7/8	2.87500	6.4918	3 13/32	3.40625	9.1126	3 15/16	3.93750	12.1768
2 57/64	2.89062	6.5626	3 27/64	3.42187	9.1964	3 61/64	3.95312	12.2736
2 29/32	2.90625	6.6337	3 7/16	3.43750	9.2806	3 31/32	3.96875	12.3708
2 59/64	2.92187	6.7052	3 29/64	3.45312	9.3652	3 63/64	3.98437	12.4684
2 15/16	2.93750	6.7771	3 15/32	3.46875	9.4501			
2 61/64	2.95312	6.8494	3 31/64	3.48437	9.5354	4	4.00000	12.5664

Mensuration Formulas

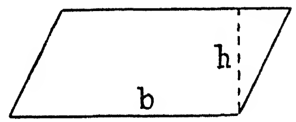
Area of *triangle* with base b and altitude h ..... $\frac{hb}{2}$.



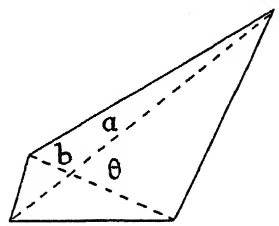
Area of *rectangle* with sides a and b is . . ab.



Area of *parallelogram* with side b and perpendicular distance to parallel side h is .... bh.



Area of any *quadrilateral* with diagonals a and b and the angle between them $\theta°$ is .... $^1/_2\, ab \sin \theta$.



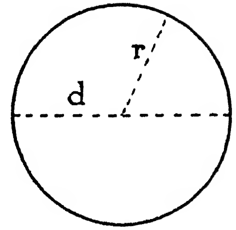
Area of *regular polygon* with n sides, each of length l, is .... $^1/_4\, nl^2 \cot \frac{180°}{n}$.

Circumference of a *circle* of radius r and diameter d, d being $2r$, is . . . . . $2\pi r = \pi d$.

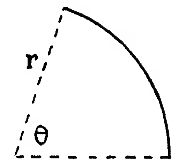
$$\pi = 3.1416 = \frac{22}{7} - 0.0012$$

Area of a *circle* is . . .

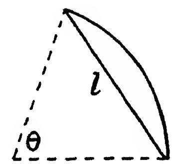
. . . . $\pi r^2 = {}^1/_4 \pi d^2$ $\quad 0.7854 d^2$ or $\frac{11}{14}\, d^2$.

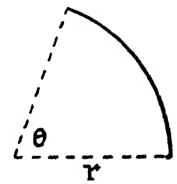


Length of an *arc* of a circle for an arc of $\theta°$ is .... $\frac{\pi r \theta}{180}$.



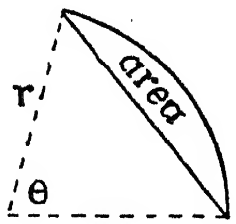
Length of a *chord* l subtending angle $\theta°$ is .... $l = 2\pi r \sin {}^1/_2\, \theta$.



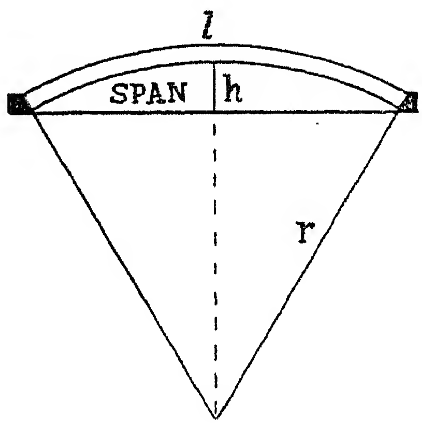


Area of a sector between radii making angle $\theta°$ is .... $\frac{\pi r^2 \theta}{360}$.

Area of a *segment* whose chord subtends $\theta°$
$\pi r^2\theta \quad r^2 \sin \theta$
360



For a *furnace crown* 1 ft. thick whose radius is equal to its span.



Outside length of crown, $l = \dfrac{2\pi(r + 1)}{6}$
$= \dfrac{22}{21}(r + 1)$ feet.

Rise of crown, inside, $h = r - r \cos 30° = 0.134r$.

Area of segment under crown is $0.091r^2$.
Number of courses of 3 in. brick in crown $= \ldots\ldots\ldots\ldots\ldots 4l = 4.19\ (r + 1)$.

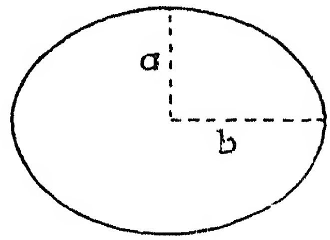
Total taper of wedges is $\dfrac{22}{21}$ ft. = 12.6 in.

Lateral area of a *regular prism* = perimeter of a right section × the length.

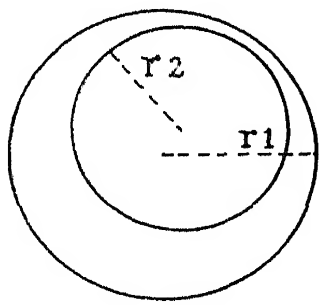
Volume of a *regular prism* = altitude × area of base.

Area of an *ellipse* is.................πab.

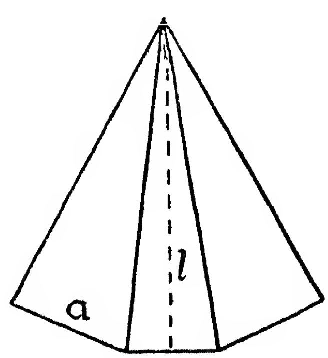
Circumference of an *ellipse* is approximately ....$2\pi\sqrt{\dfrac{a^2 + b^2}{2}}$,
where a and b are the semiaxes.



Area of a *ring* of outer radius r_1, and inner radius r_2, is..............$\pi(r_1^2 - r_2^2)$. The two circles may be concentric, or not.



Lateral area of a *regular pyramid* having slant height l, length of each side of base a, and number of sides n.. $= \frac{1}{2}\, nal$.



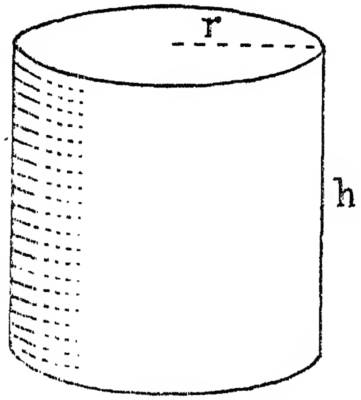
Volume of *pyramid* = ...$^1/_3$ altitude × area of base.

Surface of a *sphere* = ...$4\pi r^2 = \pi d^2 = 12.67r^2$.

Volume of *sphere* = ...$^4/_3\pi r^3 = {}^1/_6\pi d^3 = 4.189r^3$.

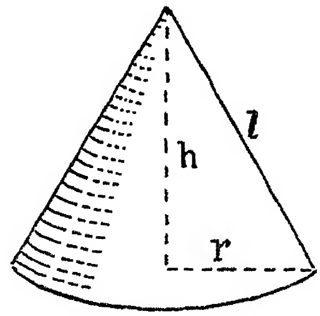
Curved surface of a *right cylinder* of radius r and altitude h is...............$2\pi rh$.

Volume of a *cylinder*...............$\pi r^2 h$.

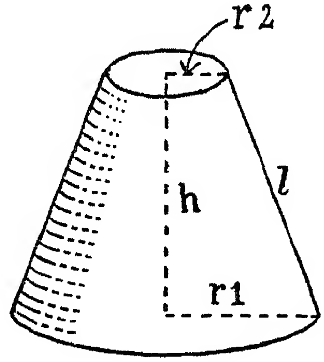


A *mushroom valve* is wide open when the cylindrical orifice formed = area of circular opening; that is, when.......... ....$2\pi rh = \pi r^2$; $h = \frac{r}{2} = \frac{d}{4}$.

Curved surface of a *right cone*, altitude h, radius r, is............$\pi r\sqrt{r^2 + h^2}$; or, for slant height l, the surface is...πrl.



Curved surface of *frustum of right cone*, radius of base r_1, and of top r_2, and altitude h is..$\pi(r_1 + r_2)\sqrt{h^2 + (r_1 - r_2)^2}$. or, for slant height l, the surface is...... ....$\pi(r_1 + r_2)l$.



Volume of the *frustum of a right cone* is.. ....$\pi\frac{h}{3}(r_1^2 + r_1r_2 + r_2^2)$.

Source: C. R. Handbook.

Standard Deviation

Used in analyzing data

Standard deviation, usually denoted by σ_x (sigma) is the most universally used measure of dispersion. It is defined as the square root of the mean of the squares of all the individual deviations measured from the arithmetic mean. The formula is:

$$\sigma_x \quad \sqrt{\frac{\Sigma X^2}{N}} = \sqrt{\frac{\Sigma(X - M_x)^2}{N}}$$

in which x = Deviation of any term or observation from the arithmetic mean.

N = The number of terms or observations.

X = Any single value of the variable.

M = The arithmetic mean.

Section III

CONVERSION TABLES

Conversion Tables

Fractional Inch to Decimals and Millimeters

In.	Decimal In.	Mm.	In.	Decimal In.	Mm.
1/64	0.0156	0.40	33/64	0.5163	13.10
1/32	0.0313	0.79	17/32	0.5313	13.49
3/64	0.0469	1.19	35/64	0.5469	13.89
1/16	0.0625	1.59	9/16	0.5625	14.29
5/64	0.0781	1.98	37/64	0.5781	14.68
3/32	0.0937	2.38	19/32	0.5938	15.08
7/64	0.1094	2.78	39/64	0.6094	15.48
1/8	0.1250	3.18	5/8	0.6250	15.88
9/64	0.1406	3.57	41/64	0.6406	16.27
5/32	0.1563	3.97	21/32	0.6563	16.67
11/64	0.1719	4.37	43/64	0.6719	17.07
3/16	0.1875	4.76	11/16	0.6875	17.46
13/64	0.2031	5.16	45/64	0.7031	17.86
7/32	0.2188	5.56	23/32	0.7187	18.26
15/64	0.2344	5.95	47/64	0.7344	18.65
1/4	0.2500	6.35	3/4	0.7500	19.05
17/64	0.2656	6.75	49/64	0.7656	19.45
9/32	0.2812	7.14	25/32	0.7813	19.84
19/64	0.2969	7.54	51/64	0.7969	20.24
5/16	0.3125	7.94	13/16	0.8125	20.64
21/64	0.3281	8.33	53/64	0.8281	21.03
11/32	0.3437	8.73	27/32	0.8437	21.43
23/64	0.3594	9.13	55/64	0.8594	21.83
3/8	0.3750	9.53	7/8	0.8750	22.23
25/64	0.3906	9.92	57/64	0.8906	22.62
13/32	0.4063	10.32	29/32	0.9062	23.02
27/64	0.4219	10.72	59/64	0.9219	23.42
7/16	0.4375	11.11	15/16	0.9375	23.81
29/64	0.4531	11.51	61/64	0.9531	24.21
15/32	0.4688	11.91	31/32	0.9687	24.61
31/64	0.4844	12.30	63/64	0.9844	25.00
1/2	0.5000	12.70	1	1.0000	25.40

Millimeter-Inch Equivalents

Mm.	In.	Approx. Fractional In.
0.5	0.020	1/50
1	0.039	1/25
2	0.079	5/64
3	0.118	7/64
4	0.157	5/32
5	0.197	13/64
6	0.236	15/64
7	0.275	9/32
8	0.314	5/16
9	0.354	23/64
10	0.394	25/64
11	0.433	7/16
12	0.472	15/32
13	0.512	33/64
14	0.551	35/64
15	0.591	19/32
16	0.630	5/8
17	0.669	43/64
18	0.709	45/64
19	0.748	3/4
20	0.787	25/32
21	0.827	53/64
22	0.866	7/8
23	0.906	29/32
24	0.945	15/16
25	0.984	63/64
25.4	1.000	...

Baumé Hydrometer

For Liquids Heavier than Water

To convert Baumé degrees into specific gravity, divide 145 by the difference between 145 and the number of Baumé degrees:

$$\text{Sp. gr.} = \frac{145}{145 - \text{Bé.}}$$

To convert specific gravity into Baumé degrees, subtract from 145 the quotient obtained by dividing 145 by the specific gravity:

$$\text{Bé.} = 145 - \frac{145}{\text{Sp. gr.}}$$

Baumé Hydrometer

For Liquids Lighter than Water

To convert Baumé degrees into specific gravity, divide 140 by the sum of 130 plus the degrees Baumé:

$$\text{Sp. gr.} = \frac{140}{130 + \text{Bé.}}$$

To convert specific gravity into Baumé degrees, subtract 130 from the quotient obtained by dividing 140 by the specific gravity:

$$\text{Bé.} = \frac{140}{\text{Sp. gr.}} - 130$$

For Light Liquids

Conversion to Density at 4°C. (39°F.)

°Bé.	D.	°Bé.	D.
10.00	1.00	50.00	0.772
11.41	0.99	51.82	0.77
12.86	0.98	54.21	0.76
14.33	0.97	55.00	0.757
15.00	0.964	56.67	0.75
15.83	0.96	59.19	0.74
17.37	0.95	60.00	0.737
18.94	0.94	61.78	0.73
20.00	0.933	64.44	0.72
20.54	0.93	65.00	0.712
22.17	0.92	67.18	0.71
23.85	0.91	70.00	0.70
25.00	0.903	72.90	0.69
25.56	0.90	75.00	0.683
27.30	0.89	75.88	0.68
29.09	0.88	78.95	0.67
30.00	0.875	80.00	0.667
30.92	0.87	82.12	0.66
32.79	0.86	85.00	0.651
34.71	0.85	85.38	0.65
35.00	0.848	88.75	0.64
36.67	0.84	90.00	0.637
38.68	0.83	92.22	0.63
40.00	0.827	95.00	0.622
40.73	0.82	95.81	0.62
42.84	0.81	99.51	0.61
45.00	0.80	100.00	0.609
47.22	0.79	103.33	0.60
49.49	0.78	...	...

A.P.I. Scale—Specific Gravity

Degrees A.P.I. =

$$\frac{141.5}{\text{sp. gr. } 60/60°} - 131.15$$

Equivalent Heat Units

British thermal units (B.t.u.) = lb. (water or equiv.) × °F. rise or fall of temp.

Kilo-Calories (Cal.) = Kg. (water or equiv.) × °C. rise or fall of temp.

1 B.t.u. = 0.2521 Cal.

1 Cal. = 3.967 B.t.u.

1 B.t.u./lb. 0.5556 (or 5/9) Cal./kg.

1 Cal./kg. = 1.80 (or 9/5) B.t.u./lb.

1 B.t.u./ft.^{3} = 8.897 Cal./m.^{3}

1 Cal./m.^{3} = 0.1124 B.t.u./ft.^{3}

1 B.t.u./ft.^{2} = 2.712 Cal./m.^{2}

1 Cal./m.^{2} = 0.3687 B.t.u./ft.^{2}

1 B.t.u./ft.^{2}/°F. = 4.883 Cal./m.^{2}/°C.

1 Cal./m.^{2}/°C. = 0.2048 B.t.u./ft.^{2}/°F.

Temperature Conversions
(see Chart, Page 36)

To change Centigrade to Fahrenheit, multiply by 9/5 and add 32.

To change Fahrenheit to Centigrade, subtract 32 and multiply remainder by 5/9.

That is:

$$F. = (C. \times 1.8) + 32; \quad C. = \frac{F. - 32}{1.8}$$

The Centigrade degree is a longer temperature interval than the Fahrenheit degree in the ratio of 9:5.

Solutions

A solution containing 1 g. per 100 cc. (or equivalent) is essentially a 1 per cent solution. Strictly speaking, especially for higher concentrations:

$$\frac{\text{Wt. of solute} \times 100}{\text{Wt. of solute} + \text{wt. of solvent}} = \%$$

1 gal. water at 39°F. = 8.34 lb.

1 gal. water at 68°F. = 8.33 lb.

Conversion Factors for Concentrations

G./100 Cc.	G./L.	Oz./Gal.	Grains/Gal.	Parts per Million
1	10	1.335	584	10^4
0.1	1	0.1335	58.4	1000
0.749	7.49	1	437.5	7490
1.712×10^{-3}	1.712×10^{-2}	2.88×10^{-3}	1	17.12
10^{-4}	10^{-3}	1.335×10^{-3}	0.0584	1

Equivalent Units

The Meaning of "$\times 10^n$" (See Following Tables)

When either very large numbers or numbers containing several zeros between the decimal point and the first significant figure are to be written, it is customary, and it saves space, to use the powers of ten. For example:

2.540×10^8 means $2.540 \times 100{,}000{,}000 = 254{,}000{,}000$

This is the same as moving the decimal point eight places to the right and filling in with ciphers. A minus exponent means division; that is:

$$10^{-4} = 1 \div 10{,}000 = 0.0001$$

Here the decimal point was moved four places to the left.

$$3.937 \times 10^{-9} = 3.937 \div 0.000000001 = 0.000000003937$$

This is sometimes written $0.0_8 3937$. Either of these clumsy forms may well be replaced by the neater expression first mentioned.

EQUIVALENT LENGTHS

Å.	mμ	μ	Mm.	Cm.	M.	In.	Ft.
1	0.1	10^{-4}	10^{-7}	10^{-8}	10^{-10}	3.937×10^{-9}	3.281×10^{-10}
10	1	10^{-3}	10^{-6}	10^{-7}	10^{-9}	3.937×10^{-8}	3.281×10^{-9}
10^4	10^3	1	10^{-3}	10^{-4}	10^{-6}	3.937×10^{-5}	3.281×10^{-6}
10^7	10^6	10^3	1	0.1	10^{-3}	3.937×10^{-2}	3.281×10^{-3}
10^8	10^7	10^4	10	1	10^{-2}	0.3937	0.0328
10^{10}	10^9	10^6	10^3	100	1	39.37	3.281
2.540×10^8	2.540×10^7	2.540×10^4	25.40	2.540	0.0254	1	0.0833
3.048×10^9	3.048×10^8	3.048×10^5	304.8	30.48	0.3048	12	1

Sources: Various reference works. Material rearranged and data recalculated.

METRIC AND AVOIRDUPOIS WEIGHTS: EQUIVALENTS

G.	Kg.	Metric Ton	Grain	Ounce	Pound	Ton
1	0.001	1×10^{-6}	15.43	0.03527	0.0022	1.1×10^{-6}
1000	1	0.001	15.43×10^3	35.27	2.2046	0.0011
10^6	1000	1	15.43×10^6	35.27×10^3	2.2×10^3	1.1023
0.0648	6.48×10^{-5}	6.48×10^{-8}	1	2.285×10^{-3}	1.428×10^{-4}	7.14×10^{-8}
28.35	0.02835	2.835×10^{-5}	437.5	1	0.0625	3.125×10^{-5}
453.6	0.4536	4.536×10^{-4}	7000	16	1	5×10^{-4}
9.072×10^5	907.2	0.9072	14×10^6	32×10^3	2000	1

PRESSURE AND STRESS UNITS: EQUIVALENTS

Mm. Hg	Water, In.	Lb. per In.^{2}	Ton per Ft.^{2}	Kilo per Mm.^{2}	Normal Atm.	Kilobar
1	0.5352	0.01934	1.392×10^{-3}	1.36×10^{-5}	1.316×10^{-3}	1.33×10^{-6}
1.869	1	0.03614	2.60×10^{-3}	2.54×10^{-5}	2.458×10^{-3}	2.491×10^{-6}
51.715	27.67	1	7.2×10^{-2}	7.03×10^{-4}	6.80×10^{-2}	6.89×10^{-5}
718.2	384.4	13.889	1	9.765×10^{-3}	0.9451	9.576×10^{-4}
7.355×10^4	3.938×10^4	1422	102.38	1	96.78	9.8×10^{-2}
760	406.8	14.696	1.058	1.033×10^{-2}	1	1.013×10^{-3}
7.5×10^5	4.014×10^5	14504	1044.2	10.197	986.9	1

Kilobar = 10^3 Bars = 10^9 Baryes
1 Bar = 10^6 Baryes
1 Barye = 1 dyne per sq. cm.

Work or Energy Units: Equivalents

B.t.u.	Ft.-Lb.	H. P. Hr.	Joule*	Cal.	Kg. M.	Kw. Hr.
1	777.97	3.929×10^{-4}	1054.8	0.2520	107.56	2.930×10^{-4}
1.285×10^{-3}	1	5.050×10^{-7}	1.356	3.239×10^{-4}	0.1383	3.766×10^{-7}
2545	1.980×10^{6}	1	2.685×10^{6}	641.3	2.737×10^{5}	0.7457
9480×10^{-4}	0.7376	3.725×10^{-7}	1	2.389×10^{-4}	0.1020	2.778×10^{-7}
3.969	3087	1.559×10^{-3}	4186	1	426.85	1.163×10^{-3}
9.297×10^{-3}	7.233	3.653×10^{-6}	9.807	2.343×10^{-3}	1	2.724×10^{-6}
3413	2.655×10^{6}	1.341	3.60×10^{6}	860	3.671×10^{5}	1

* The joule (absolute): = 0.99968 joule (International); = 1×10^{7} ergs.
1 therm = 100,000 B.t.u., a unit used in comparing costs.
1 gram-calorie (cal.) = 0.001 Cal.
1 Centigrade Thermal Unit (C.t.u.) = 1.80 B.t.u = 0.4536 Cal.
1 cubic centimeter-atmosphere (cc.-atm.) = 0.1013 joule.
1 cubic foot-atmosphere (cu. ft.-atm.) = 2869 joules.
1 liter-atmosphere (l.-atm.) = 101.3 joules.
1 kilojoule = 1000 joules.
1 megalerg = 10^{6} ergs. = 0.10 joule.

Units of Capacity: Equivalents

Fl. Oz.	Pint	Qt.	Gal.	Brit. Gal.	Cc.	Liter	Cu. In.	Cu. Ft.
1	0.0625	0.0313	0.0078	0.0065	29.57	0.0296	1.805	0.00105
16	1	0.5	0.125	0.104	473	0.473	28.88	0.0167
32	2	1	0.25	0.2082	946	0.946	57.75	0.0334
128	8	4	1	0.8327	3785	3.785	231	0.1337
153.7	9.608	4.804	1.201	1	4546	4.546	277.4	0.1605
0.0338	0.0021	0.00106	0.00026	0.00022	1	0.001	0.0610	0.000035
33.82	2.113	1.057	0.2642	0.2201	1000	1	61.02	0.03531
0.5541	0.0346	0.0173	0.0043	0.0036	16.39	0.0164	1	0.000579
957.4	59.84	29.92	7.480	6.232	28,320	28.32	1728	1

Fluid Measure (Small Units): Equivalents

Cc.	Minim	Dram	Fl. Oz.	Gill	British Fl. Oz.	British Gill
1	16.23	0.2705	0.0338	0.00845	0.0352	0.00704
0.0616	1	0.0167	0.00208	0.000521	0.00217	0.000434
3.697	60	1	0.1250	0.0312	0.1302	0.0260
29.57	480	8	1	0.250	1.041	0.2082
118.3	1920	32	4	1	4.164	0.8328
28.41	461.2	7.686	0.9608	0.2402	1	0.2000
142.0	2306	38.43	4.804	1.201	5	1

1 Gill = 0.25 Pint

Temperature Conversion Chart

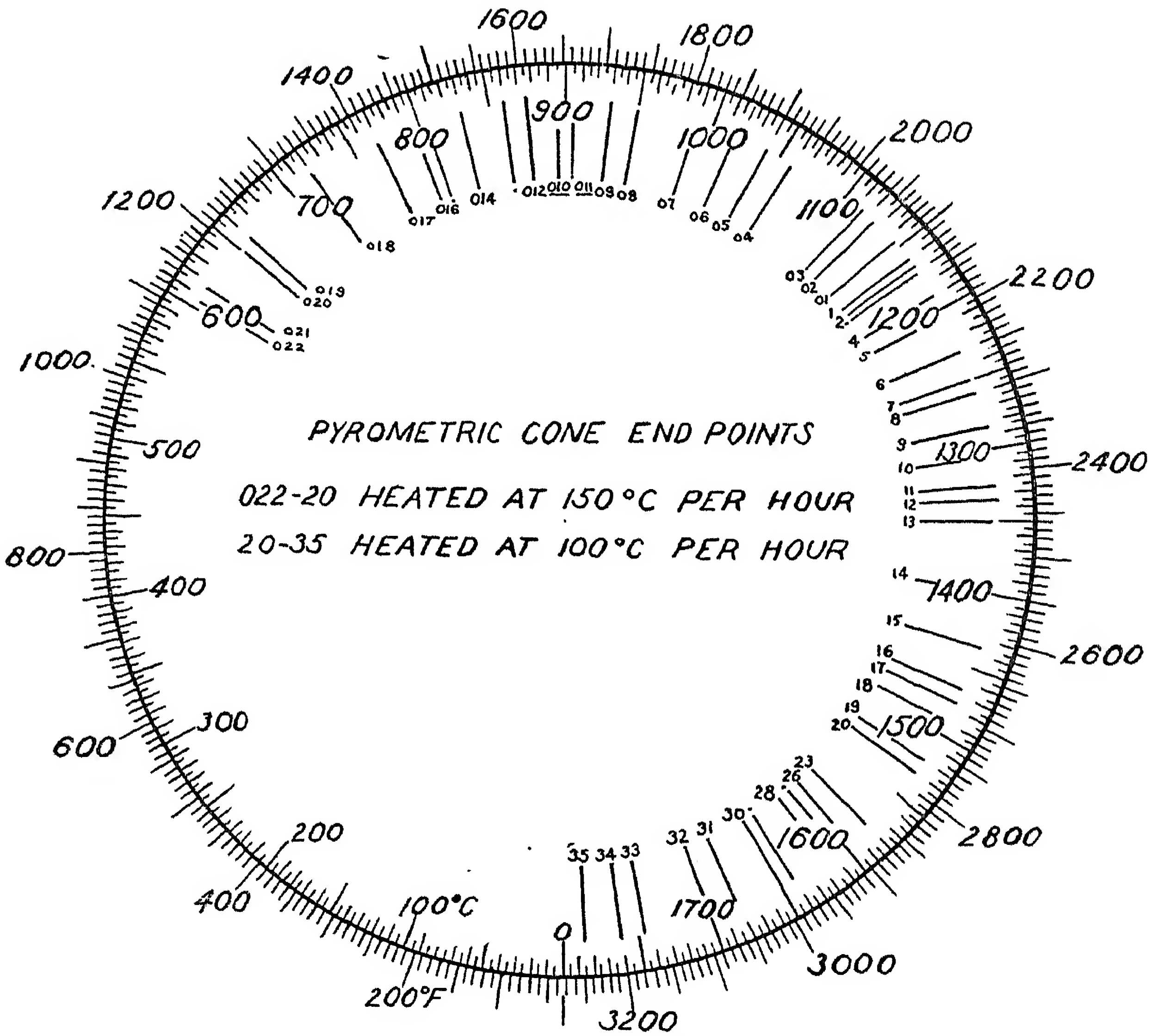
(after Albert Sauveur)

Any Centigrade temperature, in column °C., is expressed by the number of degrees Fahrenheit, read from the center column, same line. Similarly, any Fahrenheit temperature, under column °F., is expressed in Centigrade degrees by the adjacent number at the left, in the center column. The center column can be used as meaning, originally, either Centigrade or Fahrenheit; and its equivalent in Fahrenheit or Centigrade, respectively, will be found by the number at the right, or left.

°C.		°F.	°C.		°F.	°C.		°F.
−18	0	32	227	440	824	471	880	1616
−13	10	50	232	450	842	477	890	1634
− 7	20	68	238	460	860	482	900	1652
− 1	30	86	243	470	878	488	910	1670
+ 4	40	104	249	480	896	493	920	1688
10	50	122	254	490	914	499	930	1706
16	60	140	260	500	932	504	940	1724
21	70	158	266	510	950	510	950	1742
27	80	176	271	520	968	516	960	1760
32	90	194	277	530	986	521	970	1778
38	100	212	282	540	1004	527	980	1796
43	110	230	288	550	1022	532	990	1814
49	120	248	293	560	1040	538	1000	1832
54	130	266	299	570	1058	543	1010	1850
60	140	284	304	580	1076	549	1020	1868
66	150	302	310	590	1094	554	1030	1886
71	160	320	316	600	1112	560	1040	1904
77	170	338	321	610	1130	566	1050	1922
82	180	356	327	620	1148	571	1060	1940
88	190	374	332	630	1166	577	1070	1958
93	200	392	338	640	1184	582	1080	1976
99	210	410	343	650	1202	588	1090	1994
104	220	428	349	660	1220	593	1100	2012
110	230	446	354	670	1238	599	1110	2030
116	240	464	360	680	1256	604	1120	2048
121	250	482	366	690	1274	610	1130	2066
127	260	500	371	700	1292	616	1140	2084
132	270	518	377	710	1310	621	1150	2102
138	280	536	382	720	1328	627	1160	2120
143	290	554	388	730	1346	632	1170	2138
149	300	572	393	740	1364	638	1180	2156
154	310	590	399	750	1382	643	1190	2174
160	320	608	404	760	1400	649	1200	2192
166	330	626	410	770	1418	654	1210	2210
171	340	644	416	780	1436	660	1220	2228
177	350	662	421	790	1454	666	1230	2246
182	360	680	427	800	1472	671	1240	2264
188	370	698	432	810	1490	677	1250	2282
193	380	716	438	820	1508	682	1260	2300
199	390	734	443	830	1526	688	1270	2318
204	400	752	449	840	1544	693	1280	2336
210	410	770	454	850	1562	699	1290	2354
216	420	788	460	860	1580	704	1300	2372
221	430	806	466	870	1598	710	1310	2390

TEMPERATURE CONVERSION CHART (*Continued*)

°C.		°F.	°C.		°F.	°C.		°F.
716	1320	2408	1010	1850	3362	1304	2380	4316
721	1330	2426	1016	1860	3380	1310	2390	4334
727	1340	2444	1021	1870	3398	1316	2400	4352
732	1350	2462	1027	1880	3416	1321	2410	4370
738	1360	2480	1032	1890	3434	1327	2420	4388
743	1370	2498	1038	1900	3452	1332	2430	4406
749	1380	2516	1043	1910	3470	1338	2440	4424
754	1390	2534	1049	1920	3488	1343	2450	4442
760	1400	2552	1054	1930	3506	1349	2460	4460
766	1410	2570	1060	1940	3524	1354	2470	4478
771	1420	2588	1066	1950	3542	1360	2480	4496
777	1430	2606	1071	1960	3560	1366	2490	4514
782	1440	2624	1077	1970	3578	1371	2500	4532
788	1450	2642	1082	1980	3596	1377	2510	4550
793	1460	2660	1088	1990	3614	1382	2520	4568
799	1470	2678	1093	2000	3632	1388	2530	4586
804	1480	2696	1099	2010	3650	1393	2540	4604
810	1490	2714	1104	2020	3668	1399	2550	4622
816	1500	2732	1110	2030	3686	1405	2560	4640
821	1510	2750	1116	2040	3704	1410	2570	4658
827	1520	2768	1121	2050	3722	1416	2580	4676
832	1530	2786	1127	2060	3740	1421	2590	4694
838	1540	2804	1132	2070	3758	1427	2600	4712
843	1550	2822	1138	2080	3776	1432	2610	4730
849	1560	2840	1143	2090	3794	1438	2620	4748
854	1570	2858	1149	2100	3812	1443	2630	4766
860	1580	2876	1154	2110	3830	1499	2640	4784
866	1590	2894	1160	2120	3848	1454	2650	4802
871	1600	2912	1166	2130	3864	1460	2660	4820
877	1610	2930	1171	2140	3884	1465	2670	4838
882	1620	2948	1177	2150	3902	1471	2680	4856
888	1630	2966	1182	2160	3920	1476	2690	4874
893	1640	2984	1188	2170	3938	1482	2700	4892
899	1650	3002	1193	2180	3956	1487	2710	4910
904	1660	3020	1199	2190	3974	1493	2720	4928
910	1670	3038	1204	2200	3992	1499	2730	4946
916	1680	3056	1210	2210	4010	1505	2740	4964
921	1690	3074	1216	2220	4028	1510	2750	4982
927	1700	3092	1221	2230	4046	1516	2760	5000
933	1710	3110	1227	2240	4064	1521	2770	5018
938	1720	3128	1233	2250	4082	1527	2780	5036
943	1730	3146	1238	2260	4100	1532	2790	5054
949	1740	3164	1243	2270	4118	1538	2800	5072
954	1750	3182	1249	2280	4136	1543	2810	5090
960	1760	3200	1254	2290	4154	1549	2820	5108
966	1770	3218	1260	2300	4172	1554	2830	5126
971	1780	3236	1266	2310	4190	1560	2840	5144
977	1790	3254	1271	2320	4208	1565	2850	5162
982	1800	3272	1277	2330	4226	1571	2860	5180
988	1810	3290	1282	2340	4244	1576	2870	5198
993	1820	3308	1288	2350	4262	1582	2880	5216
999	1830	3326	1293	2360	4280	1587	2890	5234
1005	1840	3344	1299	2370	4298	1593	2900	5252



Temperature Comparison (Centigrade-Fahrenheit); Pyrometric Cones

Section IV

GLASS-HOUSE FUELS

Glass-House

CALORIFIC value, or heat of combustion, of fuels which are to be used in glass furnaces may be calculated from their percentage composition by volume (for the gases), using values for the low, or net, heats of combustion given in the table of Gas Constants. Values for coal must be determined by actual fuel-calorimeter tests. Values for fuel oil range from 18,000 to 19,000 B.t.u./lb., depending upon hydrogen content. Thus the heavier fuel oils, other things being equal, have greater fuel value per gallon.

By "low heat value" is meant the heat produced in combustion without taking account of the heat given off when the water vapor formed by the burning of hydrogen condenses to liquid. This amounts to 50 B.t.u./cu. ft. of hydrogen.

In the selection of values for heat of combustion for fuel gases from any reference source, care must be taken as to the conditions stated. The important conditions are whether the gas is perfectly dry or

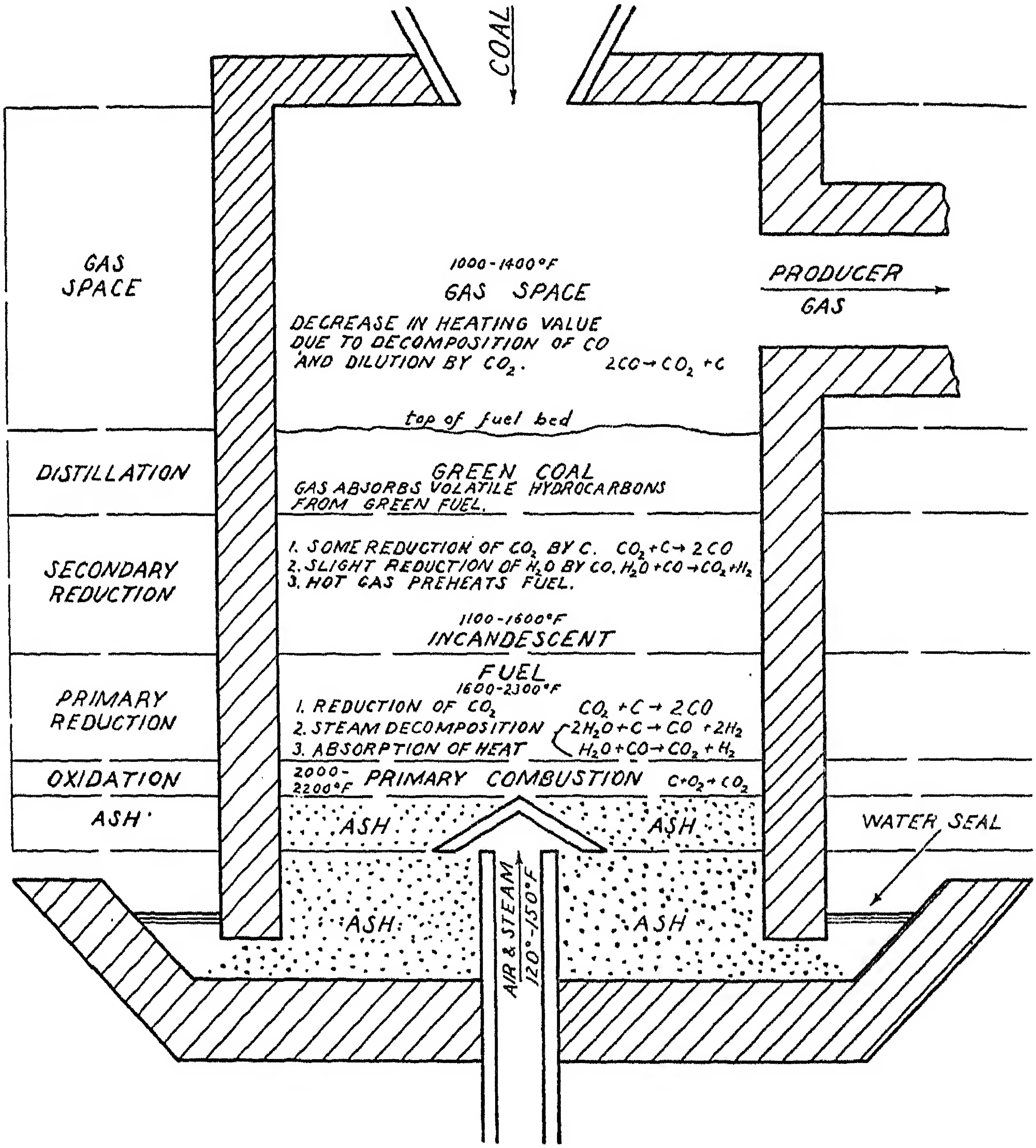
GAS CONSTANTS

At One Atmosphere Pressure and at the Freezing Point of Water

Gas	Chemical Formula	Mol. Wt.	Sp. Gr., Air = 1	Density, Lb./Ft.^{3}	Spec. Volume, Ft.^{3}/Lb.	Heat of Combustion, B.T.U./Ft.^{3} at 60 °F., Dry — Gross	Net	Air Req. for Comb., Ft.^{3}/Ft.^{3}
Acetylene	C_2H_2	26.0	0.91	0.0736	13.59	1483	1433	12.0
Air	...	28.9	1.00	0.0807	12.39	....	....	..
Butane	C_4H_{10}	58.1	2.01*	0.154*	6.50*	3261	3010	31.0
Carbon Dioxide	CO_2	44.0	1.53	0.1234	8.10	....	....	..
Carbon Monoxide	CO	28.0	0.97	0.0781	12.80	322.6	322.6	2.4
Ethane	C_2H_6	30.0	1.05	0.0847	11.81	1762	1612	16.7
Ethylene	C_2H_4	28.0	0.97	0.0781	12.80	1641	1541	14.3
Hexane	C_6H_{14}	86.1	(Liquid at low temp.)		(Calc.)	4800	4450	45.3
Hydrogen	H_2	2.0	0.07	0.0056	178.57	324.5	274.5	2.4
Methane	CH_4	16.0	0.55	0.0447	22.37	1012	912	9.5
Nitrogen	N_2	28.0	0.97	0.0781	12.80	....	....	..
Oxygen	O_2	32.0	1.10	0.0892	11.21	....	....	..
Propane	C_3H_8	44.1	1.53	0.118	8.50	2537	2330	23.8
Water	H_2O	18.0	0.62*	0.0504*	19.84*	....	....	..

* Calculated for vapor.

**Producer Diagram
Showing Reactions and
Approximate Gas Composition**



saturated with water vapor, and whether it is measured at the standard (freezing) temperature or at some more probable temperature of supply; for example, 60°F.

The manufactured and natural gases are mixtures. There is no such thing as a standard composition for a certain type of fuel gas, but there are typical ranges of composition for each. In the tabulation that follows, a typical analysis is given for a producer gas made from bituminous coal, and the method of calculating its fuel value is shown.

PRODUCER GAS, TYPICAL COMPOSITION

Constituent	Composition	Low or Net Heat of Combustion	Product
CO_2	0.05	...	..
CO	0.24	322	77
C_nH_{2n}	0.01	1540	15
H_2	0.12	274	33
CH_4	0.02	912	18
N_2	0.56	...	..
O_2	Trace; error of sampling		..
		Total fuel value	143

In addition to this fuel value, producer gas contains combustibles in the form of tar vapors and soot, which are not measurable in the analysis of the gas, but which add some small amount to the total fuel value of the gas. Carbon dioxide in producer gas represents waste and inefficient operation of the producer. The hydrogen content is greater when the coal used has a higher volatile content and when the air blast contains more steam. Typical compositions of other fuel gases are given in a table on page 44.

Air-steam ratios in the blast for gas producers are given in the following table. These ratios are based on standard atmospheric pressure, and are subject to correction for barometric reading and blast pressure, by multiplying by the fraction

$$\frac{760}{\text{Bar. read.} + \text{blast pressure, mm. Hg}}.$$

The water in the blast, as calculated, is a minimum value. It is augmented by an unknown, small amount carried mechanically as liquid water from condensation.

Producer Gas Analysis

In the analysis of producer gas in a Williams or similar apparatus, CO_2, C_nH_{2n}, and O_2 are removed in the usual manner by KOH, fuming

GAS PRODUCER BLAST DATA

Blast Temp.		V. P. of Water	% H_2O Vapor in Blast	Ratio, H_2O:Air by Volume	Ratio, H_2O:O_2 by Volume	Lb. H_2O per Lb. O_2
°C.	°F.					
50	122	93	12.2	0.140	0.67	0.37
52	126	102	13.4	0.155	0.74	0.42
54	130	112	14.7	0.173	0.82	0.46
57	135	130	17.1	0.206	0.99	0.55
60	140	149	19.6	0.244	1.16	0.65
63	145	171	22.5	0.290	1.38	0.78
66	151	196	25.8	0.348	1.66	0.93

CLEAN FUEL-GAS DATA

Gas	Composition							B.T.U./ Cu. Ft.	Cu. Ft. Air/ Cu. Ft. Gas
	CO_2	CO	C_2H_6	C_nH_{2n}	H_2	CH_4	N_2		
Coal Gas	1.0	9.0	..	6.5	47.0	34.0	2.5	550	5.4
Coke-oven Gas	1.5	5.0	..	3.0	57.5	28.5	4.5	475	4.6
Coke-oven Gas	2.5	6.0	..	5.0	48.0	34.0	4.5	535	5.3
Natural Gas, Pa.	...	...	67.0	...	..	32.3	0.7	1350	14.2
Natural Gas, Ohio	0.2	...	12.5	...	..	83.5	3.8	946	10.0
Propane	Contains 75–97% C_3H_8 plus 0–20% C_3H_6							< 2537	< 23.8

H_2SO_4, and alkaline pyrogallol, respectively. The remaining gas is then stored in a fourth pipette, over water. Its volume will be about 90 cc. (when 100 cc. sample is taken).

Take into the gas burette exactly 25 cc. air, after filling and emptying once to remove residual fuel gas from the tubes. Then take in exactly $^1/_3$ the remaining gas from storage, following by exactly 25 cc. air. This method of taking in the gas and air eliminates error from gas or air retained in the fittings.

The upper stop-cock is now closed, the lower rubber tube to the water cylinder closed by squeezing between the fingers, and the induction-coil operated, sending a spark through the mixture and exploding it. Release the rubber tube, and allow the exploded gases to cool to constant volume. Read burette-level and record contraction = (c).

Pass the gas through the KOH pipette, and record CO_2 produced by the explosion = (d).

Pass through pyrogallol, record oxygen remaining, subtract from the oxygen in the air (50 × 0.207 = *10.3*), and record oxygen consumed in the explosion = (o).

The volumes of the gases in the original sample may then be calculated as follows:

$$CO = 3(^4/_3 d + {}^1/_3 c - o)$$
$$CH_4 = 3(o - {}^1/_3 c - {}^1/_3 d)$$
$$H_2 = 3(c - o)$$

Gases

Pound-Molecular Volume, 359 cu. ft. at 1 atm. and 32°F. Or 379 cu. ft. at 1 atm. 60°F.

Gram-Molecular Volume, 22.4 liters at 1 atm. and 0°C.

Coefficient of expansion of gases, at constant pressure:

0.00203 × volume at 32°F., per °F.
0.00366 × volume at 0°C., per °C.

Gases	Specific Heat	Density, Lb./Cu. Ft., at 60°F.	"Water Value" per Cu. Ft.*
Hydrogen	3.41	0.0054	0.0184
Nitrogen	0.24	0.0749	0.0178
Oxygen	0.22	0.0856	0.0188
Carbon Monoxide	0.25	0.0749	0.0187
Carbon Dioxide	0.22	0.1185	0.0261
Steam	0.48	0.0482	0.0231

* Product of wt. per cu. ft. × sp. heat. Heat capacity in B.t.u. per °F. rise.

Formula for correcting gas volumes to new temperatures at constant pressure:

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

where V_1 = volume at absolute temperature T_1.
V_2 = volume at absolute temperature T.

Absolute temperature is 460+ °F., or 273.13+°C.

Degrees Kelvin = 273.13°C.

Example: To find the volume (V) at 1800°F. of 1000 cu. ft. of gas measured at 68°F.

$$\frac{1000}{V} = \frac{68 + 460}{1800 + 460} = \frac{528}{2260}$$

$$V = \frac{2260 \times 1000}{528} \quad 4280 \text{ cu. ft.}$$

The table on page 46 gives a number of volume ratios, and the graph on page 47 shows volume increases due to temperature.

Formula for correcting gas volumes to new pressures at constant temperatures:

$$V_1P_1 = V_2P_2$$

Formula for correcting for both temperature and pressure:

$$\frac{V_1P_1}{T_1} = \frac{V_2P_2}{T_2}$$

When gases are moist, subtract vapor pressure of water (at the temperature of the gas) from the apparent pressure.

Equal numbers of formula weights of all gases represent equal volumes, under the same conditions.

Heat of Combustion, or fuel value, is reckoned as Low or Net Value, when the water vapor formed from hydrogen-bearing gases is not condensed, as in furnace operation.

Pressure Correction Factors
For H. P. Gas Meter Readings
To Volume at 1 Atmosphere (14.7 Lb.)

Gage Pressure, Lb.	Corr. Factor	Pressure, Lb.	Corr. Factor
15	2.021	33	3.245
16	2.089	34	3.313
17	2.157	35	3.381
18	2.225	36	3.449
19	2.293	37	3.517
20	2.361	38	3.585
21	2.429	39	3.653
22	2.497	40	3.721
23	2.565	41	3.789
24	2.633	42	3.857
25	2.701	43	3.925
26	2.769	44	3.993
27	2.837	45	4.061
28	2.905	46	4.129
29	2.973	47	4.197
30	3.041	48	4.265
31	3.109	49	4.333
32	3.177	50	4.401

Composition of Dry Atmosphere at Sea Level

	% by Vol.	% by Wt.
Nitrogen	78.0	75.5
Oxygen	21.0	23.2
Argon	0.9	1.2
Carbon Dioxide	0.03	0.05
Helium	0.01	0.002
Hydrogen, Neon, etc., traces		

Source: C. R. Handbook.

At high altitudes, the contents of oxygen and carbon dioxide fall off.

Laboratory air contains definitely less than 21.0% O_2.

Some gas analysts use the figure 20.7 for oxygen.

Changes in Gas Volumes with Temperature

0° F.	32° F.	46° F.	70° F.	77° F.	230° F.	460° F.	920° F.	1380° F.	1840° F.	2300° F.	2760° F.
1.00	1.07	1.10	1.15	1.17	1.50	2.00	3.00	4.00	5.00	6.00	7.00
0.94	1.00	1.03	1.08	1.09	1.44	1.87	2.80	3.74	4.67	5.60	6.54
0.91	0.97	1.00	1.05	1.06	1.36	1.82	2.73	3.64	4.55	5.43	6.36
0.87	0.93	0.96	1.00	1.01	1.30	1.74	2.60	3.47	4.34	5.21	6.08
0.86	0.92	0.94	0.99	1.00	1.29	1.71	2.57	3.43	4.28	5.14	6.00
0.67	0.71	0.73	0.77	0.78	1.00	1.33	2.00	2.67	3.33	4.00	4.67
0.50	0.53	0.55	0.58	0.58	0.75	1.00	1.50	2.00	2.50	3.00	3.50
0.33	0.35	0.36	0.38	0.39	0.50	0.67	1.00	1.33	1.67	2.00	2.33
0.25	0.27	0.27	0.28	0.29	0.37	0.50	0.75	1.00	1.25	1.50	1.75
0.20	0.21	0.22	0.23	0.23	0.30	0.40	0.60	0.80	1.00	1.20	1.40
0.17	0.18	0.19	0.19	0.20	0.25	0.33	0.50	0.67	0.83	1.00	1.17
0.14	0.15	0.16	0.16	0.17	0.21	0.29	0.43	0.57	0.71	0.86	1.00

Temperature Correction Factor to H. P. Gas Meter Readings for Dry Gases To Volume at 60°

Temp., °F.	Corr. Factor	Temp., °F.	Corr. Factor	Temp., °F.	Corr. Factor	Temp., °F.	Corr. Factor
20	1.083	51	1.018	82	0.959	113	0.907
21	1.081	52	1.016	83	0.958	114	0.906
22	1.079	53	1.014	84	0.956	115	0.904
23	1.077	54	1.012	85	0.954	116	0.903
24	1.074	55	1.010	86	0.952	117	0.901
25	1.072	56	1.008	87	0.951	118	0.900
26	1.070	57	1.006	88	0.949	119	0.898
27	1.068	58	1.004	89	0.947	120	0.897
28	1.066	59	1.002	90	0.945	121	0.895
29	1.063	60	1.000	91	0.944	122	0.893
30	1.061	61	0.998	92	0.942	123	0.892
31	1.059	62	0.996	93	0.940	124	0.890
32	1.057	63	0.994	94	0.939	125	0.889
33	1.055	64	0.992	95	0.937	126	0.887
34	1.053	65	0.990	96	0.935	127	0.885
35	1.050	66	0.989	97	0.934	128	0.884
36	1.048	67	0.987	98	0.932	129	0.882
37	1.046	68	0.985	99	0.930	130	0.881
38	1.044	69	0.983	100	0.929	131	0.880
39	1.042	70	0.981	101	0.927	132	0.878
40	1.040	71	0.979	102	0.925	133	0.877
41	1.038	72	0.977	103	0.924	134	0.875
42	1.036	73	0.976	104	0.922	135	0.874
43	1.034	74	0.974	105	0.920	136	0.873
44	1.032	75	0.972	106	0.919	137	0.871
45	1.030	76	0.970	107	0.917	138	0.870
46	1.028	77	0.968	108	0.915	139	0.868
47	1.026	78	0.966	109	0.913	140	0.867
48	1.024	79	0.965	110	0.912	...	...
49	1.022	80	0.963	111	0.910	...	...
50	1.020	81	0.961	112	0.908	...	...

Theoretical Heat and Temperature

Theoretical heat of combustion of a fuel is:

$$Q = 81C + 290\left(H - \frac{O}{8}\right) + 25S - 6W, \text{ Cal./kg.}$$

$$= 146C + 522\left(H - \frac{O}{8}\right) + 45S - 11W, \text{ B.t.u./lb.}$$

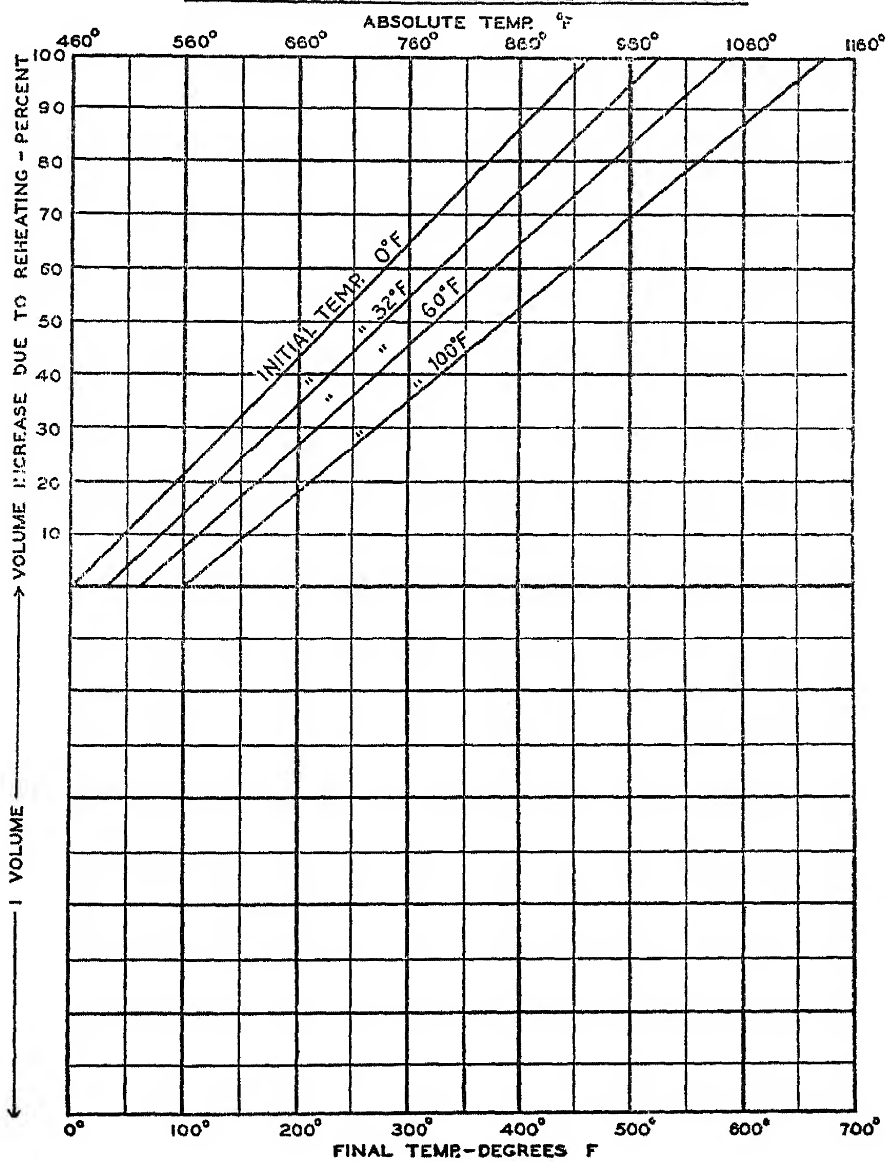
where C = % carbon; H = % hydrogen; O = % oxygen; S = % sulphur; W = % water—by weight.

Theoretical temperature is calculated:

$$T = \frac{G \cdot Q}{g \cdot S}$$

where G is the weight of fuel
Q, its heat of combustion
g, the weight of products of combustion
S, the specific heat of products of combustion.

VOLUME INCREASE DUE TO REHEATING AIR



Fuel Oil Data

	Sp. Gr.	Lb./Gal.	B.T.U. per Lb., Low Value*	B.T.U. per Gal.
Pa.	0.886	7.38	19,210	141,770
Texas	0.924	7.69	19,060	146,570
Calif.	0.950	7.91	18,720	148,100
Mexico	0.910	7.58	18,490	140,150
Residue	1.014	8.44	18,500	156,140
Gas Oil	0.860	7.16	19,760	141,480

* For oils containing 12% hydrogen, add 1050 to get gross heat value.

Approximate Range of Chemical Composition:

C	80–86%
H_2	10–14%
$N_2 + O_2$	0.5– 3%
S	Trace– 3%

Specific Heat: 0.4 to 0.5.

Coefficient of Expansion:

Average Coefficient (e)	°A.P.I. Range
0.00035	0 to 14.9
0.00040	15.0 to 34.9
0.00050	35.0 to 50.9

$$V_t = V_0(1 + te)$$

where V_0 = volume at initial temperature; t = increase in temperature, °F; e = average coefficient of expansion; and V_t = volume at new temperature.

Fuel Oil Combustion Data

B.t.u. per lb. increases with hydrogen content, for equal or not materially lower carbon content. Hence, reasonably clean oils have higher B.t.u. per lb. ratings as the density decreases according to:

$$\text{B.t.u. per lb.} = 18{,}650 + 40(°\text{Bé} - 10)$$

Specific Gravities, Pound per Gallon, and Gallons per Pound, Corresponding to the Designated Degrees A.P.I.

Deg. A.P.I.	Sp. Gr. at 60/60 °F.	Lb. per Gal.	Gal. per Lb.
0	1.0760	8.962	0.1116
1	1.0679	8.895	0.1124
2	1.0599	8.828	0.1133
3	1.0520	8.762	0.1141
4	1.0443	8.698	0.1150
5	1.0366	8.634	0.1158
6	1.0291	8.571	0.1167
7	1.0217	8.509	0.1175
8	1.0143	8.448	0.1184
9	1.0071	8.388	0.1192
10	1.0000	8.328	0.1201
11	0.9930	8.270	0.1209
12	0.9861	8.212	0.1218
13	0.9792	8.155	0.1226
14	0.9725	8.099	0.1235
15	0.9659	8.044	0.1243
16	0.9593	7.989	0.1252
17	0.9529	7.935	0.1260
18	0.9465	7.882	0.1269
19	0.9402	7.830	0.1277
20	0.9340	7.778	0.1286
21	0.9279	7.727	0.1294
22	0.9218	7.676	0.1303
23	0.9159	7.627	0.1311
24	0.9100	7.578	0.1320
25	0.9042	7.529	0.1328
26	0.8984	7.481	0.1337
27	0.8927	7.434	0.1345
28	0.8871	7.387	0.1354
29	0.8816	7.341	0.1362
30	0.8762	7.296	0.1371
31	0.8708	7.251	0.1379
32	0.8654	7.206	0.1388
33	0.8602	7.163	0.1396
34	0.8550	7.119	0.1405
35	0.8498	7.076	0.1413
36	0.8448	7.034	0.1422
37	0.8398	6.993	0.1430
38	0.8348	6.951	0.1439
39	0.8299	6.910	0.1447
40	0.8251	6.870	0.1456
41	0.8203	6.830	0.1464
42	0.8155	6.790	0.1473
43	0.8109	6.752	0.1481
44	0.8063	6.713	0.1490

Source: National Standard Petroleum Oil Tables, National Bureau of Standards, Circular C-410.

Weight of air for combustion is:

$$0.115C + 0.345\left(H - \frac{O}{8}\right) + 0.435 =$$

lb. air per lb. oil

where C = % carbon; H = % hydrogen; O = % oxygen; S = % sulphur.

The *volume* of air required is:

$$1.426C + 4.278\left(H - \frac{O}{8}\right) + 5.33S =$$

cu. ft. air per lb. oil

For a typical fuel oil, containing 85% carbon, 13% hydrogen, and 1% sulphur, the calculated air required is 14.6 lb. per lb., or 182 cu. ft. per lb., or 1376 cu. ft. per gal.

EQUIVALENT FUEL COSTS

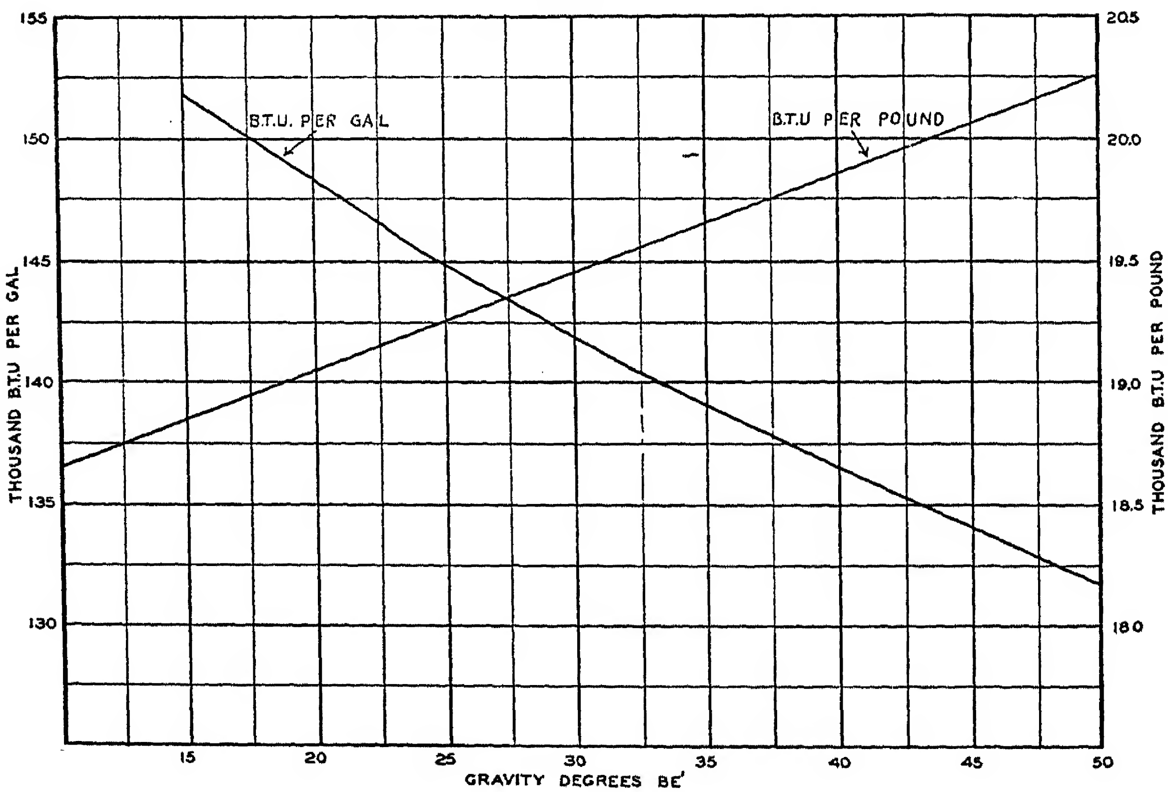
Fuel	Price per Unit				
Natural Gas—1000 B.T.U./-Cu. Ft.					
Cost per 1000 Cu. Ft.	0.10	$ 0.20	$ 0.30	$ 0.60	$ 1.20
City Gas—550 B.T.U./Cu. Ft.					
Cost per 1000 Cu. Ft.	0.055	0.11	0.165	0.33	0.66
Mixed Gas—880 B.T.U./Cu. Ft.					
Cost per 1000 Cu. Ft.	0.08	0.16	0.24	0.48	0.96
Producer Gas—150 B.T.U./-Cu. Ft.					
Cost per 1000 Cu. Ft.	0.015	0.03	0.045	0.09	0.18
Coke—12,000 B.T.U./Lb.					
Cost per Net Ton	2.40	4.80	7.20	14.40	28.80
Coal—13,000 B.T.U./Lb.					
Cost per Net Ton	2.60	5.20	7.80	15.60	31.20
Coal—14,000 B.T.U./Lb.					
Cost per Net Ton	2.80	5.60	8.40	16.80	33.60
Fuel Oil—140,000 B.T.U./Gal.					
Cost per Gallon	0.014	0.028	0.042	0.084	0.168
Fuel Oil—145,000 B.T.U./Gal.					
Cost per Gallon	0.015	0.029	0.043	0.087	0.174
Fuel Oil—150,000 B.T.U./Gal.					
Cost per Gallon	0.015	0.030	0.045	0.090	0.180
Butane (liquid)—102,400 B.T.U./Gal.					
Cost per Gallon	0.010	0.020	0.031	0.061	0.122
Butane (gas)—3200 B.T.U./ Cu. Ft.					
Cost per 1000 Cu. Ft.	0.32	0.64	0.96	1.92	3.84
Propane (liquid)—91,800 B.T.U./Gal.					
Cost per Gallon	0.009	0.018	0.028	0.055	0.110
Propane (gas)—2,550 B.T.U./-Cu. Ft.					
Cost per 1000 Cu. Ft.	0.255	0.51	0.765	0.153	3.06
Electricity—3412 B.T.U./-Kw. Hr.					
Cost per Kilowatt Hour	0.0003	0.0007	0.0010	0.0020	0.0041

Courtesy Hauck Manufacturing Co.

Vapor Pressure of Water

Temperature °C.	°F.	Vapor Pressure Mm. Hg	In. H_2O	Temperature °C.	°F.	Vapor Pressure Mm. Hg	In. H_2O
0	32.0	4.6	2.5	20	68.0	17.5	9.4
1	33.8	4.9	2.6	21	69.8	18.6	9.9
2	35.6	5.3	2.8	22	71.6	19.8	10.6
3	37.4	5.7	3.1	23	73.4	21.1	11.3
4	39.2	6.1	3.3	24	75.2	22.4	12.0
5	41.0	6.5	3.5	25	77.0	23.8	12.7
6	42.8	7.0	3.7	26	78.8	25.2	13.5
7	44.6	7.5	4.0	27	80.6	26.7	14.3
8	46.4	8.0	4.2	28	82.4	28.3	15.1
9	48.2	8.6	4.6	29	84.2	30.0	16.0
10	50.0	9.2	4.9	30	86.0	31.8	17.0
11	51.8	9.8	5.2	31	87.8	33.7	18.0
12	53.6	10.5	5.6	32	89.6	35.7	19.1
13	55.4	11.2	6.0	33	91.4	37.7	20.2
14	57.2	12.0	6.4	34	93.2	39.9	21.3
15	59.0	12.8	6.8	35	95.0	42.2	22.6
16	60.8	13.6	7.3	36	96.8	44.6	23.9
17	62.6	14.5	7.8	37	98.6	47.1	25.2
18	64.4	15.5	8.3	38	100.4	49.7	26.6
19	66.2	16.5	8.8	..	...	...	...

APPROXIMATE HEATING VALUE OF FUEL OILS
(HIGH)



Section V

COMPRESSED AIR

Compressed Air

Discharge of Air through High Pressure Orifice

In Cubic Feet of Free Air per Minute at Standard Atmospheric Pressure of 14.7 Lb. per Sq. In. Absolute and 70°F. Temperature

Gage Pressure before Orifice in Lb. per Sq. In.	Diameter of Orifice						
	1/64 In.	1/32 In.	1/16 In.	1/8 In.	1/4 In.	3/8 In.	1/2 In.
	Discharge in Cubic Feet of Free Air per Minute						
15	0.105	0.420	1.68	6.72	26.9	60.5	108
20	0.123	0.491	1.96	7.86	31.4	70.7	126
25	0.140	0.562	2.25	8.89	35.9	80.9	144
30	0.158	0.633	2.53	10.1	40.5	91.1	162
35	0.176	0.703	2.81	11.3	45.0	101	180
40	0.194	0.774	3.10	12.4	49.6	112	198
45	0.211	0.845	3.38	13.5	54.1	122	216
50	0.229	0.916	3.66	14.7	58.6	132	235
60	0.264	1.06	4.23	16.9	67.6	152	271
70	0.300	1.20	4.79	19.2	76.7	173	307
80	0.335	1.34	5.36	21.4	85.7	193	343

Table is based on 100% coefficient of flow. For well-rounded entrance multiply values by 0.98. For sharp-edged orifices a multiplier of 0.65 may be used for approximate results. Air is considered discharged to normal atmosphere.

Approximate Amount of Air Required to Cool a Plunger or Blank

In Cubic Feet of Free Air per Minute at Various Pressure Flowing from a Round Hole into the Atmosphere

Receiver Gage Pressure, Lb.	Diameter of Orifice								
	1/64 In.	1/32 In.	1/16 In.	1/8 In.	1/4 In.	3/8 In.	1/2 In.	5/8 In.	3/4 In.
	Discharge in Cubic Feet of Free Air per Minute								
10	0.0842	0.342	0.136	5.45	21.8	49	87	136	196
15	0.103	0.418	1.67	6.65	26.70	60	107	167	...
20	0.119	0.485	1.93	7.7	30.8	69	123	...	...
25	0.133	0.54	2.16	8.6	34.5	77	138	...	...
30	0.156	0.632	2.52	10	40	90	...	...	...
35	0.173	0.71	2.80	11.2	44.7	100	...	...	...
40	0.19	0.77	3.07	12.27	49.09	110.45	...	...	...
45	0.208	0.843	3.36	13.4	53.8	121	...	...	...
50	0.225	0.914	3.64	14.50	58.2	130	...	...	...
60	0.26	1.05	4.2	16.8	67	151	...	...	...
70	0.295	1.19	4.76	19	76	171	...	...	...

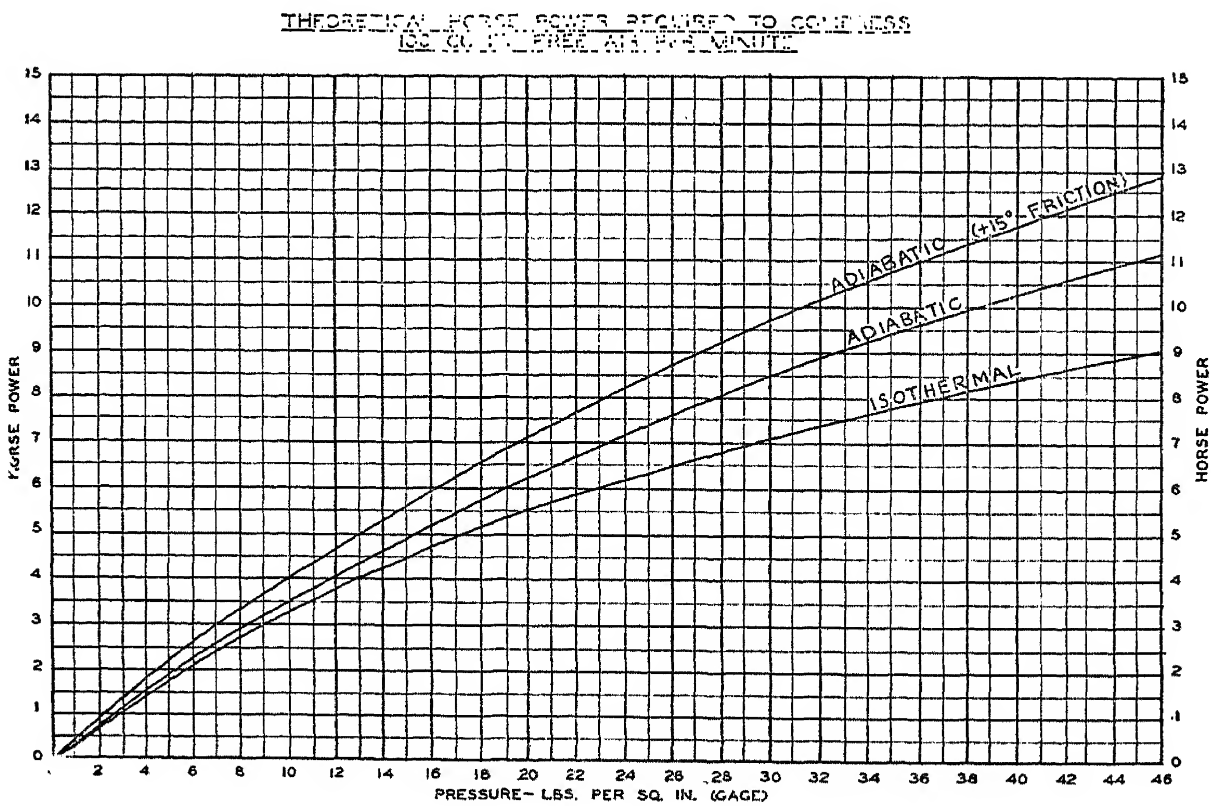
Carrying Capacity Standard Pipe—Compressed Air or Gas

Nominal Pipe Size	1/4 I. D. Tube	1/8	1/4	3/8	1/2	3/4	1	1 1/4	1 1/2	2	2 1/2	3
Actual I. D.	0.25	0.27	0.364	0.494	0.623	0.824	1.05	1.38	1.61	2.07	2.47	3.07
Relative Carrying Capacity $\sqrt{(\text{I. D.})^5}$	0.0313	0.0378	0.0799	0.1715	0.3063	0.6161	1.130	2.24	3.29	6.16	9.58	16.51

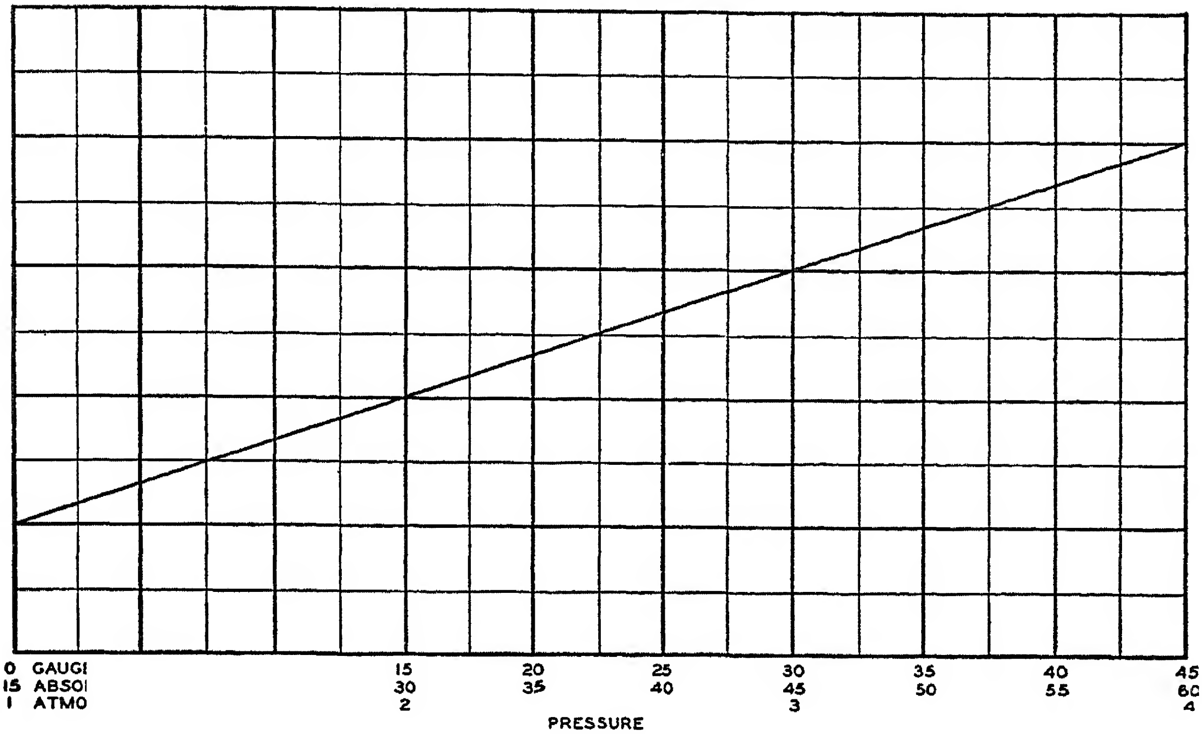
Computed by W. T. Honiss on basis given in *Glass*, November, 1926.
Actual carrying capacity of pipe depends upon pressure and friction losses.

Fans for Low-Pressure Wind

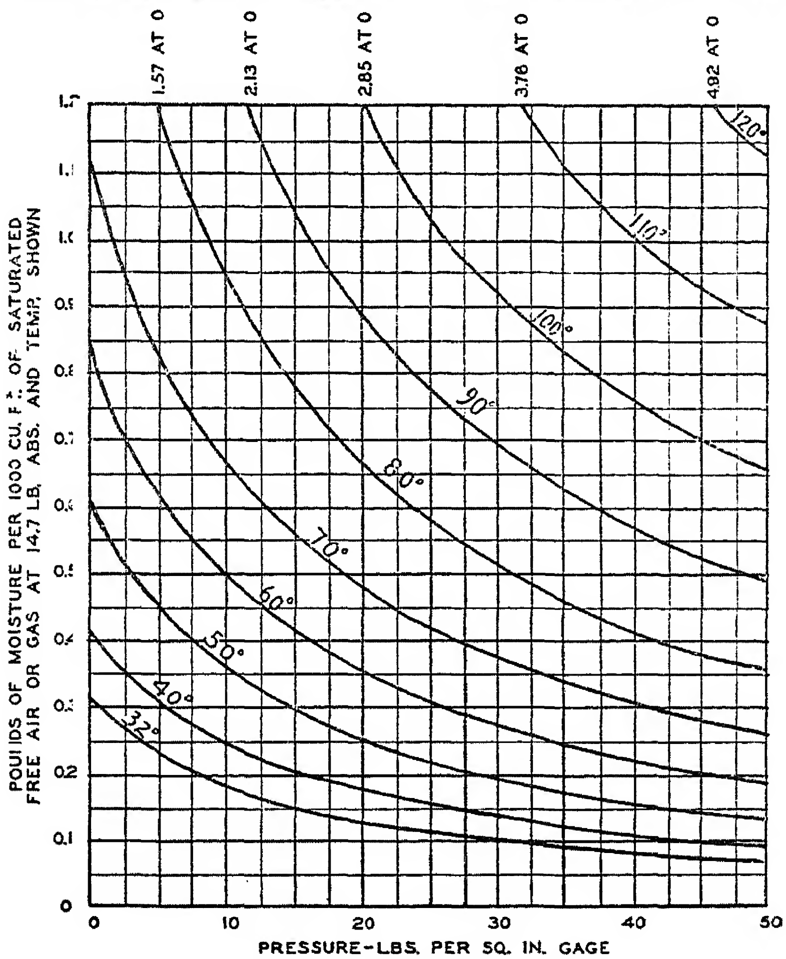
Cu. Ft./Min.	Static Pressures, H. P. 1 In.	3 In.	5 In.	10 In.	13 In.
2,000	0.5	1.3	2.2	..	..
4,000	1.0	2.6	4.4	9.9	13.0
8,000	2.0	5.2	8.8	19.8	25.0
12,000	2.6	8.0	13.2	26.6	35.0
16,000	3.6	10.5	17.5	36.2	46.0
20,000	4.3	13.0	22.0	45.0	59.0
30,000	6.5	19.5	33.0	68.0	86.0

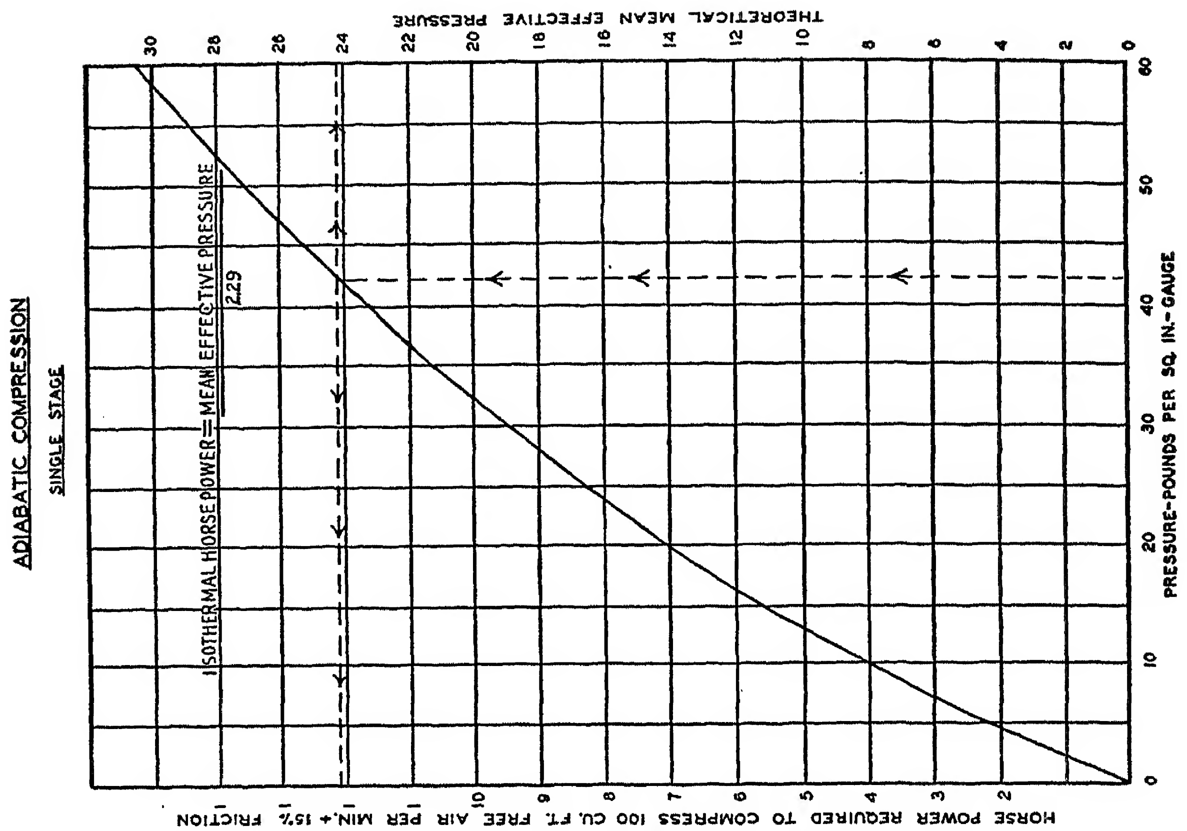


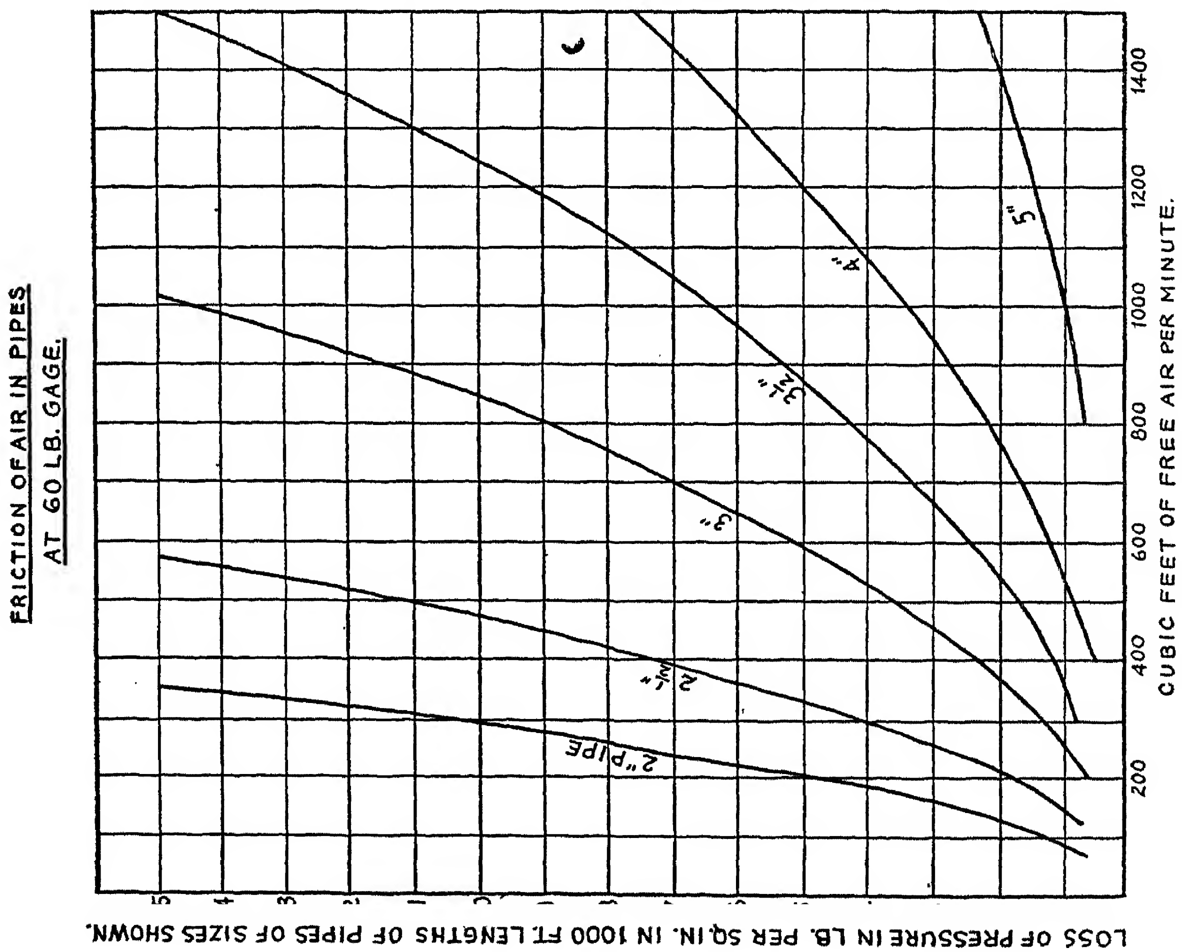
:URVE FOR REDUCING VOLUME OF AIR MEASURED AT VARIOUS PRESSURES
TO STANDARD VOLUME – 30" HG.



MOISTURE REMAINING IN SATURATED AIR OR GAS WHEN
COMPRESSED TO ANY PRESSURE AND COOLED TO TEMP SHOWN




ADIABATIC COMPRESSION
SINGLE STAGE
ISOTHERMAL HORSE POWER = MEAN EFFECTIVE PRESSURE / 2.29
THEORETICAL MEAN EFFECTIVE PRESSURE
PRESSURE-POUNDS PER SQ. IN.-GAUGE
HORSE POWER REQUIRED TO COMPRESS 100 CU. FT. FREE AIR PER MIN. + 15% FRICTION


FRICTION OF AIR IN PIPES
AT 60 LB. GAGE.
2" PIPE
2½"
3"
3½"
4"
5"
CUBIC FEET OF FREE AIR PER MINUTE.
LOSS OF PRESSURE IN LB. PER SQ. IN. IN 1000 FT. LENGTHS OF PIPES OF SIZES SHOWN.

Section VI

PROPERTIES OF GLASSES

Properties of Glasses

Definition of Glass Varieties

Name	*General Description*	*Characteristics*
Fused Silica	Pure SiO_2	Lowest expansion; greatest chemical durability; best light transmission
Heat-Resisting	Borosilicate	Low expansion; great durability
Thermometer	Borosilicate	Small "after-working"
Plate	Soda-Lime	Durability
Window	Soda-Lime	Durability; workability
Container	Soda-Lime-Magnesia-Alumina	Workability
Bulb	Soda-Lime-Magnesia	Extreme workability
Tubing	Soda-Lime-Magnesia-Alumina	Workability; controlled expansion
Tableware	(*a*) Like container glass	Color, workability, durability
	(*b*) Potash-lead	Color, luster, tone
Optical	Many compositions	Fixed optical properties; high homogeneity

Typical Glass Compositions
In Oxides Per Cent

No.	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
	Pyrex Type	Thermometer	Plate	Window	Bottle or Container	Bulb	Tubing	Lime Tableware	Lead Tableware	Optical; Flint	Optical; Crown	Spectacle
SiO_2	81.0	72.9	72.7	72.0	74.0	73.6	72.1	74.0	67.0	49.8	69.6	73.0
Al_2O_3	2.0	6.2	0.5	0.6	1.0	1.0	1.6	0.5	0.4	0.1	..	..
B_2O_3	12.0	10.4	..	..	..	..	..	..	..	..	9.9	..
SO_3	..	..	0.5	0.7	Tr.	..	..	..	..	..	..	..
CaO	..	0.4	13.0	10.0	5.4	5.2	5.6	7.5	..	..	..	12.0
MgO	..	0.2	..	2.5	3.7	3.6	3.4	..	..	..	..	..
BaO	..	..	..	..	Tr.	..	..	..	..	13.4	2.5	..
PbO	..	..	..	..	..	..	..	..	17.0	18.7	..	..
Na_2O	4.5	9.8	13.2	14.2	15.3	16.0	16.3	18.0	6.0	1.2	8.4	14.0
K_2O	..	0.1	..	..	0.6	0.6	1.0	..	9.6	8.2	8.4	1.0
ZnO	..	..	..	..	..	..	..	..	..	8.0	..	..
As_2O_5	..	Tr.	Tr.	Tr.	Tr.	Tr.	..	Tr.	Tr.	0.5	0.3	Tr.

Batches

To Make 1000 Lb. Each of the Glasses in the Preceding Table. Arsenic, Decolorizers, Colorants, and Minor Refining Agents Are Omitted

No.	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Sand	810	729	727	720	703	700	661	740	670	498	696	730
Alumina Hydrate	30	95	(3)	...	...	...	...	...	...	...	...	...
Feldspar	...	...	...	...	55	55	88	...	...	...	...	...
Borax (2)	...	288	...	...	...	...	...	...	...	...	274	...
Boric Acid (1)	214	...	...	...	...	...	...	...	...	...	...	...
Lime	...	...	130	63	...	...	...	...	...	ZnO 80	...	...
$CaCO_3$	...	...	(4)	...	...	...	...	135	...	...	...	214
Dol. Lime	...	7	...	62	91	88	90	...	...	...	...	...
$BaCO_3$	...	...	...	...	...	...	...	...	...	174	33	...
PbO	...	...	...	...	...	...	...	...	170 (6)	187	...	...
Soda Ash	77	89	182	200	227	240	275	287	103	21	144	240
Salt Cake	...	...	60	60	5	5	5	...	...	...	...	...
Coal	...	...	4	4	...	...	...	...	...	...	...	...
$NaNO_3$	...	...	...	...	...	...	...	37 (5)	...	...	...	...
KNO_3	...	2	...	...	...	...	...	...	33	30	35	22
$K_2CO_3 \cdot 1\frac{1}{2}H_2O$	...	...	...	...	...	...	...	...	144	114	124	...

Notes:
(1) Theoretical amounts are given. More may be necessary to make up for volatilization of B_2O_3
(2) Dehydrated borax may be used; 52% as much is required.
(3) When not more than 0.6% Al_2O_3 is present, this is assumed to be acquired from raw materials and refractories, and no source is provided.
(4) When limestone ($CaCO_3$) is used, 1.78 times as much is required.
(5) For melting in covered pots.
(6) Red lead is sometimes preferred; 2% more is required.

Displacement of Glass

Fluid Ounces (as of Water) Displaced by n Avoirdupois Ounces of Glass of Various Specific Gravities, at 68°F.

Sp. Gr.	Avoirdupois Ounces of Glass n									
	1	2	3	4	5	6	7	8	9	10
2.250	0.43	0.85	1.28	1.71	2.14	2.56	2.99	3.42	3.84	4.27
2.400	0.40	0.80	1.20	1.60	2.00	2.40	2.80	3.20	3.60	4.00
2.450	0.39	0.78	1.18	1.57	1.96	2.35	2.74	3.14	3.53	3.92
2.500	0.38	0.77	1.15	1.54	1.92	2.30	2.69	3.07	3.46	3.84
2.700	0.36	0.71	1.07	1.42	1.78	2.14	2.49	2.85	3.20	3.56
3.000	0.32	0.64	0.96	1.28	1.60	1.92	2.24	2.56	2.88	3.20

1 Fl. oz. of water, 29.57 cc., weighs 29.57 grams = 456.4 grains.
1 Avoir. oz. = 28.35 grams = 437.5 grains.
1 Cc. water weighs 1 gram = 15.43 grains.

Specific Gravity

(Same as metric density, or grams per cc.)

$$\text{Sp. gr.} = \frac{\text{Weight in air}}{\text{Loss of weight in water}}$$

(Usually taken at 68°F. or 20°C.)

Specific gravity × 0.578 = Ounces per cubic inch

Specific gravity × 62.4 = Pounds per cubic foot

$$\frac{32.4}{\text{Sp. gr.}} = \text{Cubic feet per ton}$$

The Estimation of Specific Gravity from Composition

If it is assumed that glasses are made up of uncombined oxides mutually dissolved, and that each of these oxides has its own specific volume at all times, the specific volume of a glass can be calculated by multiplying the per cent of each oxide by a factor representing the specific volume of that oxide, adding these products and thus obtaining a number representing the volume in cc. of 100 g. of the glass. Dividing 100 by this specific volume number gives the specific gravity.

For limited ranges of compositions, factors can be derived which will yield close approximations to observed values. One set of these values, empirically worked out, and useful more particularly for the common commercial glasses, is given below, together with an example illustrating the method of estimating specific gravity.

Specific Volume Factors

Oxide	Factor	Log
SiO_2	0.447	9.6503 − 10
Al_2O_3	0.364	9.5611 − 10
B_2O_3	0.526	9.7210 − 10
Na_2O	0.310	9.4914 − 10
K_2O	0.310	9.4914 − 10
CaO	0.218	9.3385 − 10
MgO	0.255	9.4065 − 10
BaO	0.139	9.1430 − 10
PbO	0.097	9.9868 − 10
ZnO	0.168	9.2253 − 10

Example:

Composition*	Factor		Product, Cc.
SiO_2	74.6 × 0.447	=	33.35
Al_2O_3	0.5 × 0.364	=	0.18
Na_2O	14.2 × 0.310	=	4.40
CaO	10.4 × 0.218	=	2.27
MgO	0.3 × 0.255	=	0.08
	Volume of 100 g.	=	40.28

$$\frac{100}{40.28} = 2.483, \text{ g./cc. or sp. gr.}$$

Observed, 2.484.*

* English and Turner, *J. Soc. Glass Tech.*, (1921), p. 278.

Data for Typical Glasses

	Sp. Gr.	Oz./In.^{3}	Lb./Ft.^{3}	Ft.^{3}/T.	In.^{3}/Fl. Oz.
Fused Silica	2.20	1.27	137	14.7	....
Container Glass	2.46	1.42	153	13.2	0.72 (hot)
Plate Glass	2.50	1.45	156	13.0	....
Heavy Lead Glass	3.20	1.85	199	10.1	....

Hardness of Glass

"Hardness," as meaning ability to resist scratching, is estimated for minerals in terms of their relative ability to scratch other minerals, in the Mohs scale. By this test, glasses seem to range between about 5.5 and 6.5, that is, all glasses will scratch apatite, some will scratch feldspar, but all glasses are scratched by quartz. An interesting fact is that all glasses scratch each other, so that they may not be sorted as to hardness by this test. Annealed specimens are definitely softer than those with compressive strain on their surfaces.

The "hardness" of glass has been studied by Peters and Knoop of the Bureau of Standards by a method which makes use of a ground diamond tool, impressed upon a polished glass surface by a known load. The tool has the shape of a blunt pyramid which produces an indentation in the glass surface, whose area can be measured. The load per unit area (kg./mm.^{2}) becomes a measure of the resistance of the glass to indentation, and this is one way of expressing "hardness." The results obtained on glass and other materials are shown in tables in the column adjoining:

TABLE I

	H
Optical Glasses, 90% PbO	188
Very Dense Flint	313
Dense Flint	339
Dense Flint	344
Medium Flint	357
Medium Flint	348
Barium Crown	385
Barium Crown	392
Light Barium Crown	419
Light Barium Crown	423
Boro-Silicate Crown	472
Boro-Silicate Crown	472
Fused Quartz	475
Bottle Glasses	
1	434
SA	436
OA	436

TABLE II—MOHS SCALE

		H
2	Gypsum	32
3	Calcite	135
4	Fluorite Clear	163
	Fluorite Milky	180
	Rockwell 25	271
5	Apatite I axis	360
5	Apatite II axis	430
6	Albite	490
6	Orthoclase	560
7	Quartz II axis	710
	Quartz I axis	790
	Rockwell 66	780
8	Topaz	1250
9	Corundum	1655
10	Silicon Carbide	2130
11	Boron Carbide	2265
12	Diamond	8200

Elasticity

Young's modulus of elasticity (E) for a series of soda lime glasses was found by Clarke and Turner to lie between 8.2×10^6 and 1.2×10^7. In these glasses, the substitution of lime for soda brings about a steady increase in the modulus. Gehlhoff and Thomas found that lime and magnesia increased this modulus, and that boron oxide first increased and then decreased it when present in larger amounts than 15%. The other oxides have little or no effect on the parent glass.

Surface Tension

The surface tension of glasses has been studied by a number of investigators, whose results, by different methods, are not in very close agreement. The most comprehensive work is that of Badger, Parmelee, and Williams, who obtained results in the neighborhood of 300 dynes per centimeter at temperatures of 1200° and 1350°C. It appears that surface tension is lowered by Na_2O, K_2O, PbO, B_2O_3, TiO_2, and very markedly by V_2O_5. It is raised by additions of other oxides, particularly by CaO, MgO, and Al_2O_3.

Abradability

Abradability, or yielding to grinding, becomes a practical measure of the ease with which glasses may be ground and polished. Some experimental values, where quartz has been used as the abrasive and the weight of glass removed in a given time from specimens in the form of rods is the measure of abradability, and where the standard of abradability is fused silica or "vitreosil," are given below:

Tentative Methods of Testing Glassware Adopted by Committee C-14, A.S.T.M.

Tentative methods thus far adopted cover:

(1) Chemical analysis of glass sands.

(2) Modulus of rupture of glass specimens.

(3) Thermal endurance of glass rods.

(4) Tests for resistance of glass bottles to internal pressure.

(5) Polariscope examination of glassware.

(6) Thermal shock resistance of glass containers.

Complete procedures following these methods may be obtained from the secretary, A.S.T.M., 260 South Broad Street, Philadelphia.

Electrical Properties

Ordinary glasses are electrolytic conductors whose specific resistivity ranges from 10^{19} ohms (cold) to 1 ohm (at 1200°C.). Moisture on glass surfaces lowers the resistance greatly.

Vitreosil	1.0
Pyrex Resistant	1.7

SiO_2	Na_2O	CaO	MgO	Al_2O_3	B_2O_3	Abradability
74	9	10	...	...	7	2.4
74	12	10	...	...	4	2.7
74	15	10	...	...	1	2.9
74	16	10	...	...	..	3.0
74	20	6	...	...	..	3.4
74	26	..	...	...	..	3.5
74	22	..	...	4	..	3.8
66	26	..	...	8	..	4.2
74	16	5.8	4.2	...	..	3.2
..	..	..	...	...	PbO	...
65	15	..	...	...	20	5.0

Softening Temperature

A glass has no melting point, but the temperature where its viscosity has been so reduced by heating that it reaches a degree of mobility, arbitrarily defined, is called its softening temperature. A number of experimental methods could be used to fix this arbitrary point.

When expansibility is measured by the interferometer, a temperature is reached at which the glass specimens yield under the weight of the quartz glass plates, and a hump appears in the expansion curve. The temperature corresponding to the maximum on this curve is sometimes chosen as the softening point.

A more convenient method, useful as a check on composition and as an indication of working temperature, is that of J. T. Littleton (*J. Am. Ceramic Soc.*, 1927, page 259). A uniform thread of the glass, 0.50–0.75 mm. in diameter, 22 cm. long, and suspended vertically so that the upper 10 cm. is heated at the rate of 5° per minute, gradually stretches under its own weight as temperature rises. When the rate of elongation becomes 1 mm. per minute, the corresponding temperature is called the softening point. The softening point, as measured by the Littleton method, corresponds to a viscosity of 4.5×10^7 poises ($\log \eta = 7.65$). The softening point as determined by the maximum on the expansion curve by interferometer corresponds to a viscosity of 10^{11} to 10^{12} poises.

Lillie (*Jour. Am. Cer. Soc.*, 1931, p. 502) measured the rate of elongation of a uniform fiber of glass 0.50–0.70 mm. diameter, 50 cm. long, heated through most of its length, and suspending a load. Viscosity was calculated from the mobility rate thus found. The rate of strain disappearance in the same glass was visually observed by polarized light, and thus viscosities at the strain point, annealing point, and softening temperature could be determined. The method of elongation of a fiber under load then became useful for direct estimation of these temperatures.

Tensile Strength

The tensile strength of any glass specimen is greatly affected by the condition of its surface, and by the nature and amount of its internal strain. Experimental values show a wide variation, depending upon the type of specimen and the method of testing used as well as upon the above conditions. Consequently, no definite values can be assigned to this property for a single composition, to say nothing of determining the effect of different oxides upon tensile strength. An estimate of 10,000 pounds per square inch cross section is reasonable for annealed specimens in the form of rods or bars about 1/4 in. in diameter. Smaller rods give higher values, and very fine fibers may exhibit strength calculated to more than five hundred thousand pounds per square inch.

Thermal Expansion

The expansibility of glasses and other substances is conveniently expressed as coefficient of linear expansion, which is the fraction of its length which a body expands per degree rise in temperature. The cubical, or volume, coefficient is three

times linear. In the following table, these coefficients are given $\times 10^{-7}$; *e. g.*, 148×10^{-7} means 0.0000148. The interval is 20°–300°C.

The thermal expansion of a glass determines its resistance to breakage by cooling shock somewhat in accordance with the following formula:

$$\theta = \frac{P}{\alpha E}$$

where θ represents the number of degrees of cooling shock necessary to break the glass, P the tensile strength and E the modulus of elasticity in the same units, and α the coefficient of linear expansion per degree.

The formula leaves out of consideration properties of the glass affecting its diffusivity for heat. It cannot take into account the varying severity of cooling shock depending upon circumstances, *i. e.*, immersion in water, glycerine, oil, or merely cold air. Consequently, the formula is of value only for the comparison of glasses which are to be chilled under the same conditions.

Moreover, no formula can provide for variations in the thermal endurance of a specimen, which depends upon thickness, shape, and distribution of glass, not to mention the degree of annealing or of disannealing. Therefore, there is no such thing as an absolute value for the thermal endurance of a glass.

The property which remains of greatest importance in estimating the thermal endurance of different glasses in whatever shape or circumstance of treatment is the coefficient of expansion.

Coefficients of Expansion of Various Glasses

Composition: Oxides per cent									$\alpha \times 10^7$ per °C.
SiO_2	Al_2O_3	Na_2O	K_2O	CaO	MgO	PbO	ZnO	B_2O_3	Range 0–100°
...	...	....	.....	....	...	....	...	100	150
100	...	....	....	....	...	....	...	.....	5
66.9	...	33.1	....	....	...	....	...	.....	135
74.0	...	26.0	....	....	...	....	...	.....	114
.....	...	30.1	....	....	...	....	...	69.9	102
74.6	...	11.3	....	....	...	....	...	14.5	62
76.0	...	12.0	....	12.0	...	....	...	.....	75
75.2	...	15.4	....	9.4	...	....	...	.....	85
74.7	...	18.4	....	6.9	...	....	...	.....	92
74.1	...	15.5	....	10.0	...	....	...	.....	86
73.4	0.9	19.5	....	....	...	....	6.1	.....	95
55.9	1.2	11.3	....	....	...	31.6	...	.....	88
59.3	...	5.0	8.0	....	...	27.5	...	.....	81
54.8	2.5	6.0	11.5	....	...	25.0	...	.....	102
76.3	0.7	18.3	....	....	5.1	....	...	.....	84
77.8	0.6	13.4	....	....	8.4	....	...	.....	65
75.6	0.9	14.5	....	5.5	3.7	....	...	.....	78
75.1	6.5	18.2	....	....	...	....	...	.....	85

In general, silica and boron oxide are the components which lower the coefficient of expansion, the alkalies raise it most, and the other oxides are intermediate. The coefficient may be estimated quite closely for common glasses by using the factors developed by English and Turner.

SiO_2	0.05×10^{-7}	CaO	1.63×10^{-7}
Al_2O_3	0.17×10^{-7}	MgO	0.45×10^{-7}
B_2O_3	-0.66×10^{-7}	PbO	1.06×10^{-7}
Na_2O	4.32×10^{-7}	ZnO	0.07×10^{-7}
K_2O	3.90×10^{-7}	BaO	1.73×10^{-7}

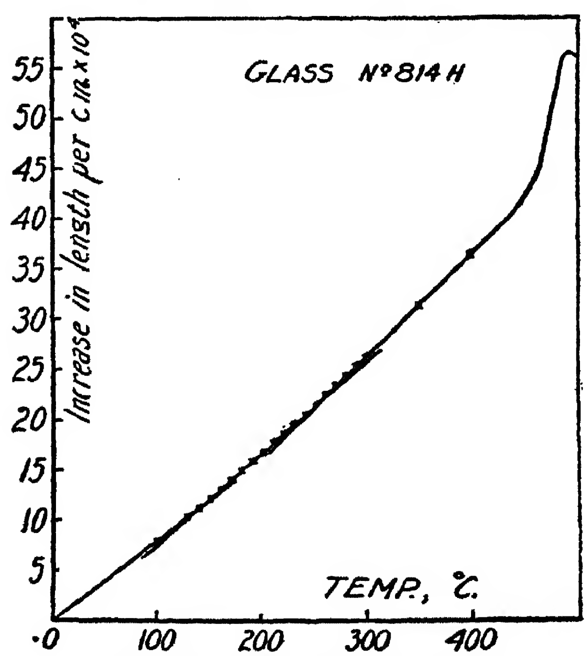
Multiply the per cent of each oxide by its factor, and add the products, to find approximate coefficient of linear expansion of the glass.

The factor for B_2O_3 is valid only for small per cents of B_2O_3—less than one-half the Na_2O content.

Expansion Curves

When the length of a glass specimen is plotted against its temperature, the graph is not a straight line but a curve, following some such equation as:

$$dl = \alpha t + \beta t^2 + \gamma t^3.$$



THERMAL EXPANSION CURVE

However, a temperature is reached where this curve breaks suddenly upward. This temperature has been called by some observers "the transformation point." It is now believed to represent rather, a region in which the glass which has previously exhibited expansion corresponding to the thermal history of the specimen now reaches more or less rapidly a new equilibrium corresponding to the higher temperature. Not only expansibility but other properties such as density and specific heat depend upon the thermal history of the glass, or the equilibrium with respect to the dissociation of its components which has been "frozen in." (See J. T. Littleton, *J. Ind. Eng. Chem.*, 1933.

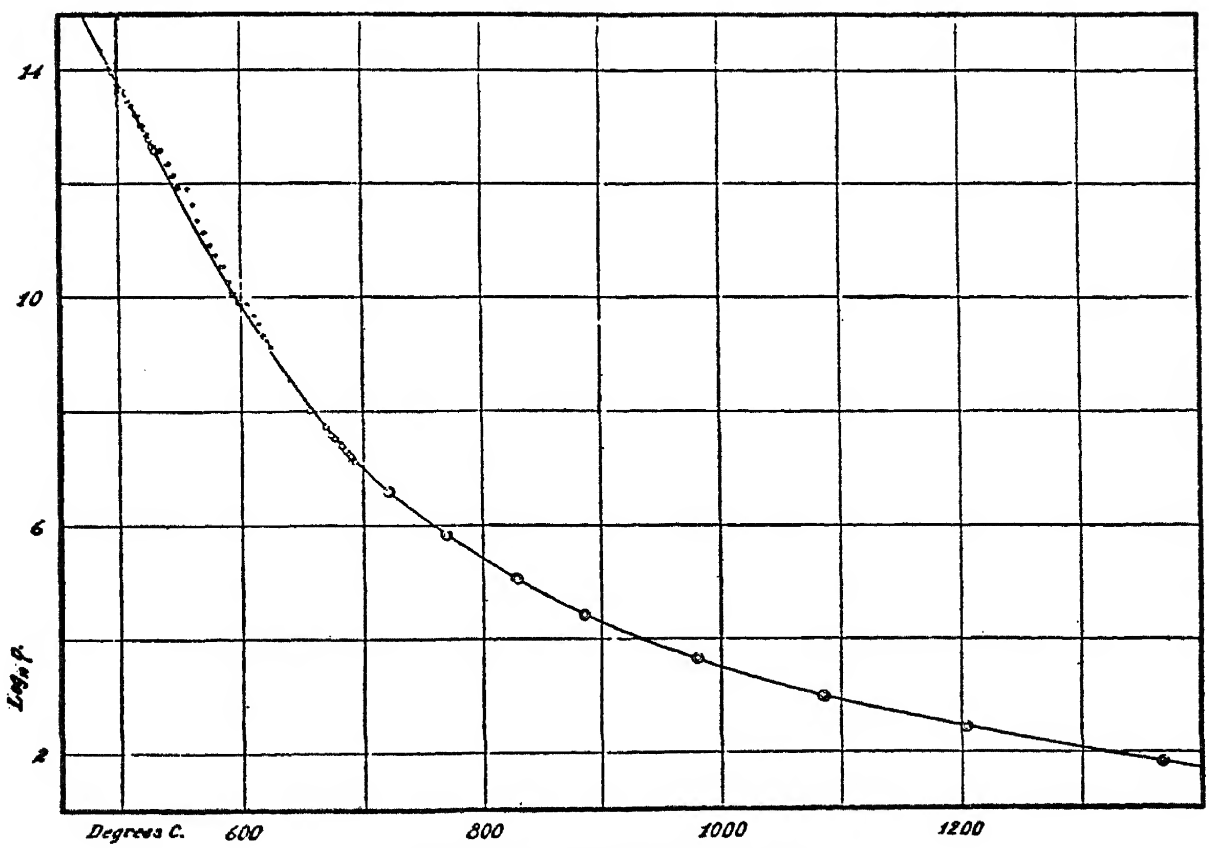
Substance	Coefficient α/°F.	Coefficient α/°C.
Aluminum, Commercial	148×10^{-7}	267×10^{-7}
Brass, Cast	106	190
Brick, Common	53	95
Brick, Fire-clay	45	81
Bronze (Inc. with Sn)	116	210
Carbon, Graphite	45	80
Cement Concrete	55–78	100–140
Copper	100	178
Duralumin	144	260
Glass*	3–67	5–120
Iron, Cast	59+	106+
Lead	165+	300+
Magnesium	150	270
Nickel Steel (36%, Invar)	5	9
Platinum	50	90
Porcelain	10–25	18–45
Silver	100+	180+
Stainless Steel	55–67	100–120
Tin	150	270
Type Metal	110	198
Zinc	150	270

* See separate table.
Source. C. R. Handbook.

Viscosity

Viscosity is the most important property of hot glass: it controls the rate of plaining; it interferes with homogeneity; by its rapid rate of change, it makes working processes possible; it enables glass to cool without crystallizing, and is responsible for the vitreous condition; it is directly concerned in the formation and relief of internal strain.

The unit of viscosity as the force required to overcome internal friction is the poise, η, dimensions $ML^{-1}T^{-1}$. It is the force in dynes required to maintain two planes, 1 cm. square, at a velocity of 1 cm./sec. with respect to each other, when separated by 1 cm. of liquid. Molten glass at the highest temperature of the furnace has a viscosity of about 10^2–10^4 poises; at the working temperature, about 10^6–10^{11}; at the annealing temperature, about 10^{14}. This very rapid rate of change of viscosity with temperature requires that viscosity curves be plotted as log η *vs.* temperature. The viscosities of glasses at high temperatures are most commonly measured by the method of Margules, in which two concentric cylinders, separated by a given thickness of the glass, are kept in rotation with respect to each other at a measured rate by a measured torque. The apparatus is calibrated against cold liquids of known viscosity. A specimen curve is illustrated for a typical lime glass.



VISCOSITY CURVE FOR GLASS

RELATIVE VISCOSITY TABLE FOR A SODA-LIME-SILICA GLASS AT HIGH TEMPERATURE

°F.	1800	1850	1900	1950	2000	2050	2100	2150	2200	2250	2300	2350	2400	2450	2500	2550	2600
2650	490	294	190	111	68	47	31	21	14	9.9	6.9	5.1	4.0	2.8	2.1	1.7	1.3
2600	363	218	140	82	50	35	23	16	11	7.2	5.1	3.8	2.8	2.1	1.6	1.2	
2550	295	177	112	67	41	28	19	13	8.7	6.0	4.2	3.1	2.3	1.7	1.3		
2500	229	138	87	52	32	22	15	10	6.8	4.6	3.2	2.4	1.8	1.3			
2450	176	106	67	40	24	17	11	7.7	5.2	3.5	2.5	1.8	1.4				
2400	129	77	49	29	18	12	8.2	5.6	3.8	2.6	1.8	1.3					
2350	97	58	37	22	13	9.2	6.2	4.2	2.8	1.9	1.4						
2300	71	43	27	16	9.8	6.8	4.5	3.1	2.1	1.4							
2250	50	30	19	11	6.8	4.7	3.2	2.2	1.5								
2200	34	20	13	7.7	4.8	3.2	2.2	1.5									
2150	23	14	8.7	5.2	3.2	2.2	1.5										
2100	16	9.4	6.0	3.5	2.2	1.5											
2050	10	6.3	4.0	2.4	1.5												
2000	7.2	4.3	2.7	1.6													
1950	4.4	2.7	1.6														
1900	2.6	1.6															
1850	1.7																

BATCH

Sand	1000
Soda Ash	350
Calcite	350
Feldspar	60
Salt Cake	7

Viscosity of glass at top temperatures is x times the viscosity of the same glass at temperatures in the left-hand column, x being the figure indicated in the table.

Annealing

Annealing is the process of removing or preventing strain.

Strain in glass is elastic deformation arising from internal stresses, caused by temperature gradients during cooling.

The "annealing range" extends from a temperature where the glass has enough internal mobility so that strains disappear in a very short time (15 min.), down to a temperature where strains will not disappear in 15 hours. The upper limit, variously specified, is called the annealing point, corresponding to a viscosity of 2.5×10^{13} poises (Lillie). The strain point represents viscosity about 16 times as great.

Some annealing temperatures given by different authorities are tabulated on page 69.

Annealing involves: (1) heating at the annealing temperature long enough for strains to disappear, and (2) cooling at a slow enough rate to prevent formation of strain.

Strain becomes visually evident when the glass is viewed by polarized light. When a tint plate is used in the polariscope, the colors produced in the same quadrant of the visible field will identify tensile and compressive strains, respectively, according to the adjustment of the polarizer and analyzer, and this can be demonstrated by experiment. This is a qualitative or at best only a relative test for strain. Comparison with standard strain

Glass	Annealing Point,		Strain Point,	
	°C.	°F.	°C.	°F.
Soda-Silica Eutectic	490	915	...	...
Lime Glasses	472–523	880–975	412–472	775–880
Window	580	1075	...	...
Soda-Alumina Silica	490	915	...	...
Soda-Alumina Silica with Slightly Higher Alumina	492	920	...	...
Soda-Alumina Silica with 9 Per Cent Alumina	510	950	...	...
Borosilicates	518–550	965–1020	470–503	875–940
Plate Glass	575	1065	...	...
Lead Glasses	419–451	785–845	353–382	665–720
English Crystal	460	860	...	...
BaO-ZnO, Borosilicate	606	1125	...	...

disks will give the examination a quantitative character; or if a polariscope is used which carries a quartz wedge, the extent of strain may be determined as well as its tensile or compressive character, by the displacement of the lines or bands in the field of this instrument.

The quantitative measure of strain is expressed in birefringence per unit length, usually in millimicrons (mμ) per centimeter. It is the difference in refractive index (reciprocal of velocity) for the light waves vibrating parallel with and normal to the axis, divided by the length of the path. The permissible strain varies according to the purpose for which the glass is to be used, and is lowest for optical glass, at about 5 mμ/cm., and some authorities propose 50 mμ/cm. for plate glass. Strain corresponding to stress sufficient to break the glass would amount to about 200 mμ/cm.

Standard Strain Disks

Reference standards for polariscope testing for strain consist of a set of five disks, individually checked for optical path difference, so mounted that they can be combined additively and their total effect observed in comparison with that of a piece of ware. The optical path difference for each is 22.8 mμ at points one-quarter of an inch from the edge. Such disks are obtainable from the Glass Container Association.

The temper or strain of the ware is given a number from 1 to 6 according to the number of disks, superposed, required to produce the same color pattern in the polariscope field.

Stress-Optical Coefficient

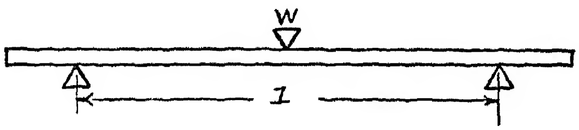
To find stress in kilograms per square centimeter, divide retardation in millimicrons per centimeter of optical path by 2.6.

Retardation in millimicrons per inch multiplied by 2.2 gives stress in pounds per square inch.

This estimate is good, for most soda-lime glasses. Lead glasses have less retardation per unit stress.

Formulas for Tests

Modulus of Rupture by Cross-Breaking



For a cylindrical rod:

$$F = \frac{8Wl}{\pi d^3}$$

where W = load in lb.
l = length between supports in inches.
d = diameter of rod, inch.
F = Modulus of Rupture, lb. per in.^{2}

For a tubular circular beam:

$$F = \frac{8Wld_1}{\pi(d_1{}^4 - d_2{}^4)}$$

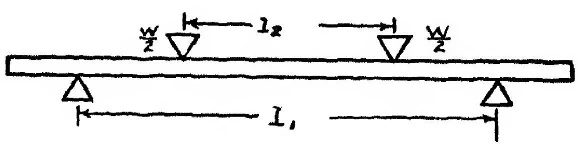
where d_1 and d_2 are outside and inside diameters, respectively.

For a rectangular beam:

$$F = \frac{3Wl}{2bd^2}$$

where b is breadth and d is depth of beam.

In a "no-shear" test, using double knife edges:



For a cylindrical rod:

$$F = \frac{8W(l_1 - l_2)}{\pi d^3}$$

If $l_2 = {}^1/_2 l_1$,

$$F = \frac{4Wl_1}{\pi d^3}$$

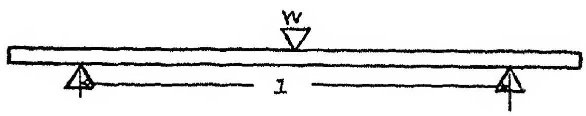
For a tube:

$$F = \frac{8W(l_1 - l_2)d_1}{\pi(d_1{}^4 - d_2{}^4)}$$

For a rectangular beam:

$$F = \frac{3}{2}\,\frac{W(l_1 - l_2)}{bd^2}$$

Young's Modulus of Elasticity (Stretching) by Cross-Bending



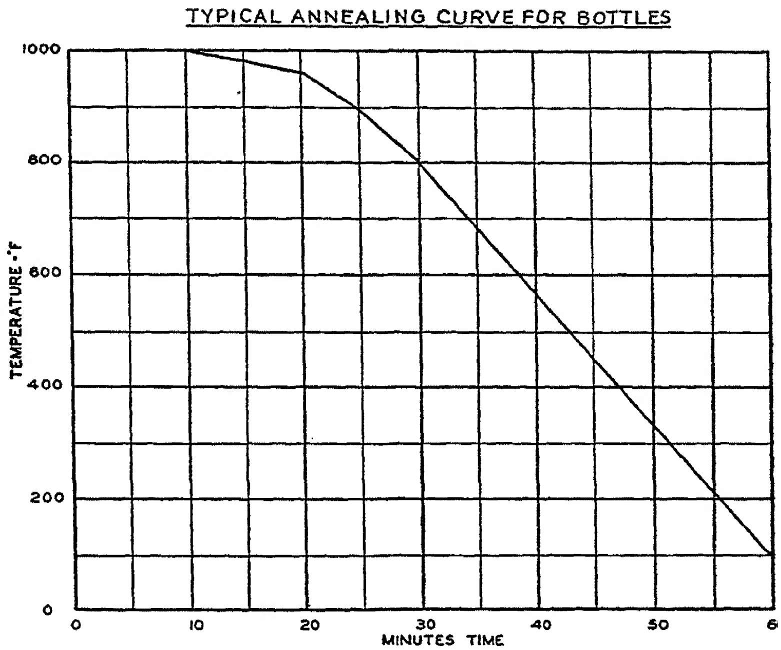
For a cylindrical rod:

$$E = \frac{4Wl^3}{3\pi\Delta d^4}$$

For a rectangular beam:

$$E = \frac{Wl^3}{4\Delta bd^3}$$

where Δ = deflection.
W is in lb., dimensions in inches.
E = Young's Modulus, lb. per in.^{2}



Durability Test

Tentative Method of the Glass Division, Amer. Ceram. Soc. (O. G. Burch, *Bull. Amer. Ceram. Soc.*, 1934, page 200).

The glass is crushed in a steel mortar having a 2-inch cavity and flat-bottomed pestle, and screened to pass 40-mesh and stay on 50-mesh sieve. The grains are washed in 95% alcohol, and dried at 110–120°C. A 10-gram sample is weighed into a 200-ml. Erlenmeyer flask, 50 ml. $N/50$ H_2SO_4 is added, and the flask is closed by a one-hole rubber stopper and heated in a thermostat at 90°C. ± 0.5° for 4 hours.

The flask is quickly cooled, and the contents are titrated directly with $N/50$ NaOH, with phenol red, bromphenol blue, or other indicator insensitive to CO_2. The volume of $N/50$ acid neutralized by the glass is found by difference, and the equivalent alkali is reported as per cent Na_2O. For ordinary bottle glass, this figure is about 0.07% Na_2O; for sheet glass, about 0.03%.

Details of the method are reported by G. E. F. Lundell, *Bull. Amer. Ceram. Soc.*, 1935, page 180.

Glass Analysis

An excellent general discussion on glass analysis by G. E. F. Lundell is found in *Jour. Ind. Eng. Chem.*, 1933, page 853.

The most recent information on short methods of analysis of glass is given by Webster and Lyle, *Jour. Amer. Ceram. Soc.*, 1940, page 235.

Comparative Expansibility Test

Small rods of two different glasses are welded side by side into a compound rod, which is then drawn into a fiber of about $^1/_2$-mm. diameter. If the expansibilities of the glasses differ, the compound fiber bends as it cools, with the glass of greater expansion (contraction) on the inside of the curve.

Section VII

FURNACES

Classification of Melting Furnaces

1. Pot furnaces.

   (*a*) Open pots, for plate glass and optical glass.

   (*b*) Covered pots, for hand-gathered pressed and blown ware.

These furnaces may be direct-fired, recuperative, or regenerative.

2. Day tanks, for hand-gathered pressed and blown ware.

These may also be direct-fired, recuperative, or regenerative.

3. Continuous tanks, necessary for mechanical glassworking.

   (*a*) Bridge wall type; (*b*) Floater type.

Usually regenerative, occasionally recuperative, seldom direct-fired.

Furnace Dimensions and Capacities

1. Optical glass furnaces are made for one or two pots, with capacity of 500–1000 lb. each.
2. Plate glass furnaces usually hold 10 pots, with capacity of approximately 3000 lb. each.
3. Covered pot furnaces of the modern type are usually circular and regenerative, and hold 8 to 16 pots of capacity approximately one ton each.
4. Capacities of day tanks may be calculated from their dimensions, allowing 150 lb. per cu. ft. In estimating the yield per melt, allowance is made for the stump, or residue of glass that cannot be gathered, which will be from 4 to 6 inches in depth. Day tanks usually range from 1 to 10 tons in capacity.
5. Continuous tanks are rated on the basis of glass worked out per day of 24 hours. Small units are not economical, and are not generally built to deliver less than 7 daily tons. Units delivering 50 daily tons are common, and a number are in use delivering upwards of 100 daily tons.

Continuous tanks are seldom direct-fired, and recuperators are not satisfactory except for the smaller units. Most continuous tanks are regenerative. The ports are commonly arranged on the sides, firing across the melting chamber; but the end-port tank, with horseshoe flame, is a satisfactory construction. Charging may be by hand, using a doghouse or a charging opening in the back wall above the glass level; it may be partly mechanical, with batch fed from an overhead hopper into a doghouse while cullet is added by hand shoveling, or it may be completely mechanical, when the cullet is ground and mixed with the batch, and the charge fed by screw-feed, vibrating, or pusher type of feeder.

The melting capacity of a continuous tank is usually determined by the area under fire, called "melt-

ing area." This is the space back of the bridge wall or back of the floaters. For window glass production, as much as 12 sq. ft. per daily ton are often provided; but for containers and tableware, modern practice requires only 6 to 8 sq. ft. per daily ton.

The depth of continuous tanks varies from 5 feet in window glass practice to 18 inches for some small units, with 30 to 42 inches the common choice for bottle tanks.

Tank capacities depend, further, upon operating temperature, character of glass produced, glass quality required, and the efficiency of the operating machines. Temperatures range from 2600° to 2900°F. Fuel consumption depends upon control of flame for best heat transfer, tank design, and efficiency of operation. It may be brought as low as 7000 cu. ft. of natural gas per ton of glass carried through, or the equivalent of this fuel in oil or in other gases. Tanks are commonly operated under a few hundredths inch positive pressure in the combustion chamber; and are usually built so that from 0.4 to 0.6 inch water-gage draft at the stack base suffices to remove the products of combustion. Continuous draft recorders placed in the stack flue ahead of the damper indicate the variation of draft with different damper settings, with changes in the outside air conditions or in tank temperatures, and with the continuous changes that take place in the regenerator temperatures. They also disclose unbalanced conditions which may result when the regenerators on one side of the tank run hotter than on the other, or for any reason show difference in resistance to flow of the waste gases.

Recording charts for tank temperatures, regenerator temperatures top and bottom, stack-flue temperatures, and draft vacuum are useful as giving a picture of the conditions of tank operation.

Pull

Rate of Drawing Glass from Tanks

When automatic machines or feeders are in steady operation, the "pull" or "load" on the tank may be calculated from the weight of the gob and the number of shear-cuts or articles made per minute.

1 oz./min. = 90 lb./day = 0.045 T/day

Let W = weight of gob in oz.; S = shear-cuts per minute; T = tons of glass drawn per day.

Then

$$T = 0.045\ WS$$

For drawn-sheet or continuous-pour processes, the calculation becomes simply

$$T = 0.045 \times \text{ounces drawn per minute}$$

Convenient rules for estimation of pull:

Gross/24 hr. = Bottles per minute × 10
Doz./24 hr. = Bottles per minute × 120
Gross/hr. = Bottles per minute × 0.416
Doz./hr. = Bottles per minute × 5
Doz./8-hr. shift = Bottles per minute × 40

GLASS DRAWN BY FEEDER, IN TONS PER DAY (24 HR.)

Shear-Cuts per Min.	Ounces per Gob													
	1	2	3	4	5	6	8	10	12	14	16	20	24	28
10	0.45	0.90	1.35	1.80	2.25	2.70	3.60	4.50	5.40	6.30	7.20	9.00	10.80	12.60
11	0.50	1.00	1.50	2.00	2.50	3.00	3.95	4.95	5.95	6.95	7.90	9.90	11.90	13.85
12	0.55	1.10	1.65	2.20	2.75	3.30	4.40	5.40	6.50	7.60	8.60	10.80	12.95	15.20
13	0.60	1.15	1.75	2.35	3.00	3.60	4.70	5.85	7.00	8.20	9.45	11.70	14.05	16.40
14	0.65	1.25	1.90	2.50	3.15	3.80	5.05	6.30	7.55	8.80	10.10	12.60	15.10	17.65
15	0.70	1.35	2.00	2.70	3.30	4.05	5.40	6.75	8.10	9.45	10.80	13.50	16.20	18.90
16	0.70	1.45	2.15	2.90	3.60	4.30	5.75	7.20	8.65	10.10	11.50	14.40	17.30	20.15
17	0.75	1.55	2.30	3.05	3.80	4.60	6.10	7.65	9.20	10.70	12.25	15.30	18.35	21.40
18	0.80	1.60	2.45	3.25	4.05	4.90	6.50	8.10	9.70	11.25	13.00	16.20	19.45	22.70
19	0.85	1.70	2.55	3.40	4.30	5.15	6.85	8.55	10.25	11.95	13.70	17.10	20.50	23.95
20	0.90	1.80	2.70	3.60	4.50	5.40	7.20	9.00	10.80	12.60	14.40	18.00	21.60	25.20
21	0.95	1.90	2.85	3.80	4.70	5.65	7.55	9.45	11.35	13.25	15.10	18.90	22.70	26.45
22	1.00	2.00	2.95	3.95	4.95	5.95	7.90	9.90	11.90	13.85	15.85	19.80	23.75	27.70
23	1.05	2.10	3.10	4.15	5.20	6.20	8.25	10.35	12.45	14.50	16.55	20.70	24.85	28.95
24	1.10	2.15	3.25	4.30	5.40	6.50	8.60	10.80	12.95	15.10	17.30	21.60	25.90	30.20
25	1.10	2.25	3.35	4.50	5.60	6.75	9.00	11.25	13.50	15.75	18.00	22.50	27.00	31.50
26	1.15	2.35	3.50	4.70	5.85	7.00	9.35	11.70	14.05	16.40	18.70	23.40	28.10	32.75
27	1.20	2.45	3.65	4.85	6.10	7.30	9.70	12.15	14.60	17.00	19.45	24.30	29.15	34.00
28	1.25	2.50	3.80	5.05	6.30	7.55	10.10	12.60	15.10	17.65	20.15	25.20	30.25	35.30
29	1.30	2.60	3.90	5.20	6.55	7.85	10.45	13.05	15.65	18.25	20.90	26.10	31.30	36.55
30	1.35	2.70	4.05	5.40	6.75	8.10	10.80	13.50	16.20	18.90	21.60	27.00	32.40	37.80
31	1.40	2.80	4.20	5.60	7.00	8.35	11.15	13.95	16.75	19.55	22.30	27.90	33.50	39.05
32	1.45	2.90	4.30	5.75	7.20	8.65	11.50	14.40	17.30	20.15	23.05	28.80	34.55	40.30
33	1.50	2.95	4.45	5.95	7.40	8.90	11.90	14.85	17.80	20.80	23.75	29.70	35.65	41.60
34	1.55	3.05	4.60	6.10	7.65	9.20	12.25	15.30	18.35	21.40	24.50	30.60	36.70	42.85
35	1.60	3.15	4.70	6.30	7.90	9.45	12.60	15.75	18.90	22.05	25.20	31.50	37.80	44.10
36	1.60	3.25	4.85	6.50	8.10	9.70	12.95	16.20	19.45	22.70	25.90	32.40	38.90	45.35
37	1.65	3.35	5.00	6.65	8.35	9.95	13.30	16.65	20.00	23.30	26.60	33.30	39.95	46.60
38	1.70	3.40	5.15	6.85	8.55	10.30	13.70	17.10	20.50	23.95	27.40	34.20	41.00	47.90
39	1.75	3.50	5.25	7.00	8.80	10.55	14.05	17.55	21.05	24.55	28.10	35.10	42.15	49.15
40	1.80	3.60	5.40	7.20	9.00	10.80	14.40	18.00	21.60	25.20	28.80	36.00	43.20	50.40

Heat Balances

The calculation of heat balance for a glass furnace involves the determination of the total heat entering the furnace as generated by combustion, and with the addition of sensible heat from the hot fuel gas in the case of producer-gas operations. This total heat is now accounted for in the following principal items: (1) useful heat in the glass; (2) heat lost through the furnace walls:

(*a*) through the crown and superstructure,

(*b*) through the tank blocks (side walls),

(*c*) through the bottom,

(*d*) through the ports and uptakes,

(*e*) through the checker chambers and flues;

(3) sensible heat carried out in the stack gases; (4) heat escaping through actual openings, or leaks in the combustion chamber (sting-out).

Although the general overall efficiency of the furnace may be conveniently and practically expressed in terms of the weight of glass delivered per unit of fuel consumed—as, for example, tons of glass per tons of coal—this over-simplified estimate gives no opportunity to suggest improvements in furnace design, or operation, such as might be pointed out by more detailed study of the losses involved.

However, these losses are difficult to estimate. Also, the actual heat required to melt the batch and cullet, depending as it does upon heats of chemical reaction of the raw materials, and the specific heat of the glass itself, have been variously estimated by different students of the problem. The flow of heat through furnace walls depends upon a number of variables such as the emissivity of surfaces, the flow of air over these surfaces as influenced by position, ventilation, or the application of fan wind, and, especially in the case of tank blocks, by the age of the furnace and the consequent thinness and wall conductivity.

Even the heat carried out through the stack can scarcely be estimated accurately because, although stack temperatures are easily measured, the total volume of stack gases is not subject to measurement but must be calculated from the quantity of fuel used, with the help of analysis of the stack gases themselves. Leaks in the flue system and variations in the firing procedure occasioned by adjustment of flame and temperature, and by variation in weather conditions, make the whole calculation inaccurate.

The part played by regenerators has been handled differently by different investigators. Some of them have assumed simply that the heat taken up by the checker bricks from the outgoing gases and transferred to the incoming air (or air and producer gas) is essentially a constant quantity of recirculated heat, appearing on both sides of the balance and therefore without influence on efficiency.

The temperature of the glass upon which the efficiency is to be based becomes an interesting question. If the furnace is being treated simply as a melting unit, this temperature is the melting-chamber temperature or the highest reached by the glass. If the more logical step is followed, of treating the furnace as an operating unit, and taking the temperature of the glass accordingly as it is delivered to the gatherer or the feeder, a much lower temperature is concerned, and, therefore, a much lower value of furnace efficiency is reached.

References

"Heat Balance of a Glass Tank." A. E. Badger, V. C. Fugman, and H. S. Vormelker. *Glass Ind.*, 16 (1935), pages 5–10.

"The Heat Balance of a Glass Furnace." R. D. Pike and G. H. West. *J. Am. Ceramic Soc.*, 11 (1928), pages 734–744.

"Efficiency of Tank Furnace for Glass Melting." W. Friedman. *J. Soc. Glass Tech.*, 14 (1930), pages 91–102.

"On a New Type Gas-Fired Furnace." M. W. Travers. *J. Soc. Glass Tech.*, 4 (1920), pages 205–225.

"Heat Balance of a Plant Consisting of an Air-Steam Blown Gas Producer and a Glass Tank Furnace." M. W. Travers. *J. Soc. Glass Tech.*, 5 (1921), pages 166–183.

"Some Technical Proposals and Data for an Examination of the Thermal Performance of Glass Melting Tanks." W. Friedman. *J. Soc. Glass Tech.*, 20 (1936), pages 596–639.

In addition to the above is a thesis by H. Maurach, treated in Chapter XI of "Glass Tank Furnaces," by Devillers and Vaerewyck (Scholes).

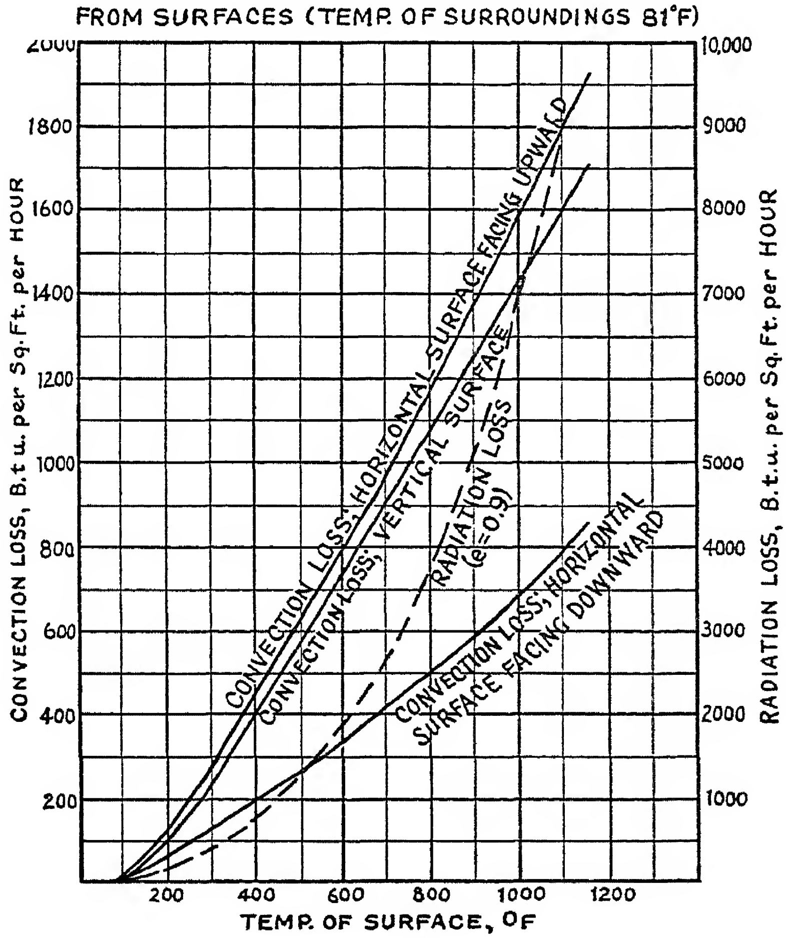
Two examples of calculations of heat balance are given below:

Heat Balance, by Badger, Fugman, and Vormelker

(*Glass Ind.*, 1935, pages 5–10)

Fuel, natural gas, in a 6-port tank.
Container glass comp., using 2000-lb. cullet to 1016-lb. batch.
Sp. heat of glass to 2290 °F. (working temp.), 0.31.
Net endothermic reactions in melting batch, 81.3 B.t.u./lb.
Temp. of melting chamber, 2640 °F.
Balance worked out on 24-hour basis.
Total glass worked in 24 hours, 99.6 tons, charged as 69.5 tons cullet, 30.1 tons new glass from batch.
Chart of radiation and convection losses:

FIGURE 4. – RADIATION AND CONVECTION LOSSES FROM SURFACES (TEMP. OF SURROUNDINGS 81°F)



Graphical representation of heat balance:

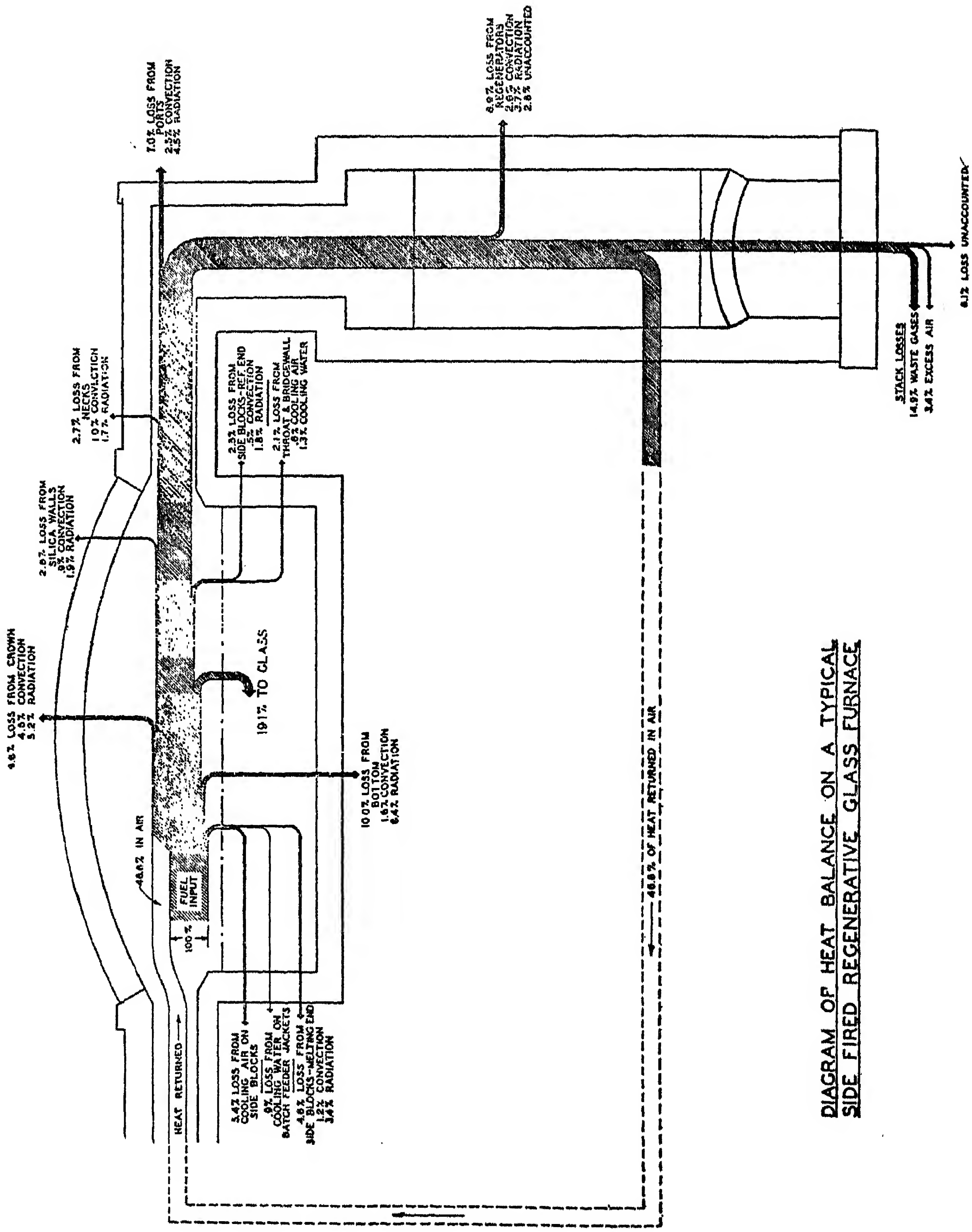


DIAGRAM OF HEAT BALANCE ON A TYPICAL SIDE FIRED REGENERATIVE GLASS FURNACE

HEAT OUTPUT—SUMMARY OF RESULTS

Description of Heat Loss	Heat Account in 1000 B.T.U. per 24 Hours	Heat Account in 1000 B.T.U. per Ton of Glass Melted	Heat Account in Percentage of Total Input	
For Thermochemical Reactions	4,895		0.7	
For Raising Temp. of Cullet and Glass Formed from Batch to Temp. of Refining End	137,500		18.4	
Total Utilized for Glass-melting	142,395(t)	1,430		19.1
Sensible Heat in Stack Gases	110,700		14.9	
Sensible Heat in Excess Air of Combustion at Stack	25,840		3.4	
Total Stack Loss	136,540(t)	1,371		18.3
Radiation Losses from Surfaces				
Crown	38,800		5.2	
Bottom	62,500		8.4	
Melting End Side Blocks	25,500		3.4	
Refining End Side Blocks	13,450		1.8	
Ports	33,190		4.5	
Necks	12,952		1.7	
Silica Walls	13,840		1.9	
Regenerators	27,565		3.7	
Total Radiation Loss from Surfaces	227,797(t)	2,288		30.6
Convection Losses from Surfaces				
Crown	34,200		4.6	
Bottom	11,990		1.6	
Melting End Side Blocks	9,470		1.2	
Refining End Side Blocks	4,095		0.5	
Ports	18,404		2.5	
Necks	7,230		1.0	
Silica Walls	6,540		0.9	
Regenerators	19,340		2.6	
Total Convection Loss from Surfaces	111,269(t)	1,117		14.9
Picked Up by Regenerators from Waste Gases	(413,824)		(55.5)	
Delivered by Regenerators to Air of Combustion	(347,740)		(46.6)	
Unaccounted-for Loss in Regenerative System (in Flues)	19,179(t)	191.8		2.6
Cooling Water				
Throat and Bridgewall Coils	9,700		1.3	
Batch Feeder Jackets	6,500		0.9	
Total	16,200(t)	162.6		2.2
Cooling Air				
Throat and Bridgewall	6,100		0.8	
Side Blocks, Melting End	40,500		5.4	
Total	46,600(t)	467.8		6.2
Unaccounted-for Losses	45,855(t)	460.4		6.1
TOTALS	745,835(t)	7,488.6		100.0

Heat Balance, by H. Maurach

("Glass Tank Furnaces," Chap. XI)

THE PRODUCERS

	B.T.U.	%
Separate Items:		
Coal to Gas-Producers, 3800 Lb./Hr.	42,955,000	96.52
Air-Steam Blast	1,548,000	3.48
Chemical Energy of Dry Gas	32,554,000	73.18
Chemical Energy of Tar and Oil	1,997,000	4.48
Sensible Heat of Dry Gas	4,430,000	9.94
Sensible Heat of Steam	1,128,000	2.54
Total Heat of the Gas	40,109,000	90.14
Losses: In Clinkers and Ash		0.58
In Dust		0.36
By Radiation and Conduction (difference)		8.92
Producer Efficiency, 90%		

THE GLASS

Batch, 4596 lb./hr.
75% yield
Of glass, 3447 lb./hr.
Cullet, 2133 lb./hr.
Sp. heat of glass (est.), 0.32
Endothermic reactions in batch consume 490 B.t.u./lb.
Combustion:
Producer gas was heated by regenerators to 1735°F.
Air gas was heated by regenerators to 2120°F.
Excess of air found was 5.5%.
Flame temperature, 2910°F.
Glass bath temperature, 2550°–2600°F.

SUMMARY OF HEAT BALANCE

Input, %		Output, %	
Coal	95.10	Heat Utilized in Glass	12.80
Steam	3.73	Losses in Waste Products:	
Batch	1.17	Condensation of Steam	0.03
		Ash and Dust	0.57
	100.00	Gas at Reversals	1.72
Regenerated Air	12.40	Flue Gases up the Stack	29.92
		Losses by Radiation and Conduction:	
		Flues to Gas Producers	0.93
		Producers and Mains	8.75
		Gas Flue	3.32
		Regenerators	5.83
		Tank	40.30
		Flue to Stack	8.23
	112.40		112.40

Heats of Fusion and Reaction

In any attempt to work out a heat balance, or determine efficiency, for a glass-melting furnace, the "chemical heat" involved in reactions between batch ingredients must be taken into account, and also the heats of fusion of the glass formers.

Unfortunately, data on these matters are quite incomplete. Some of the heats of fusion, marked "Est.," below, are estimated from the behavior of related compounds. Values for a number of materials, such as feldspar and borax, are entirely lacking. The heat of vaporization of water is included, because it is obviously one of the items of heat expenditure in the melting of a glass batch containing either hydrated materials or free water.

In the table, the underlined formulas represent the material concerned as weight in the last two columns. A plus (+) sign means heat evolved; a minus (−) sign means heat absorbed or required to bring about fusion or reaction, respectively. "Cal." refers to kilogram-calories.

Stack Draft

Draft is caused by the excess buoyancy of hot air or gases. It is called a "pull" or "vacuum," but is actually the thrust or pressure of the atmosphere. Draft exists in every hot flue that is vertical or inclined, and is responsible for the intake of air into hot regenerators, the resistance of hot regenerators or recuperators to the downward flow of com-

	Cal./G. Mol.	Cal./ Kg.	B.T.U./ Lb.
$\underline{SiO_2}$	− 3	− 50	− 90
$\underline{CaCO_3} \rightarrow CaO + CO_2$	− 42	−420	−756
$\underline{CaO} + SiO_2 \rightarrow CaSiO_3$ (Glass)	+ 21	+375	+675
$\underline{Na_2CO_3} + SiO_2 \rightarrow Na_2SiO_3$ (Cryst.)	− 6	− 56	−100
$\underline{Na_2SiO_3}$, Fusion (Est.)	− 5	− 40	− 72
$\underline{Na_2CO_3}$, Fusion (Est.)	− 4	− 38	− 68
$\underline{MgCO_3} \rightarrow MgO + CO_2$	− 28	−333	−600
$\underline{CaCO_3 \cdot MgCO_3} \rightarrow CaO + MgO + 2CO_2$	− 70	−380	−684
$\underline{NaNO_3}$, Fusion	− 3	− 33	− 60
$\underline{2NaNO_3} + SiO_2 \rightarrow Na_2SiO_3 + 2NO + 3O$	+ 40	+235	+423
$\underline{H_2O}$, Vaporization	− 10	−540	−972
$\underline{Na_2B_4O_7 \cdot 10H_2O}$, Vaporization of H_2O	−100	−260	−468
$\underline{Ca(OH)_2} \rightarrow CaO + H_2O$ (Steam)	− 27	−364	−656
$\underline{BaCO_3} \rightarrow BaO + CO_2$	− 64	−320	−576
$\underline{BaSO_4} \rightarrow BaO + SO_3$	−107	−460	−828
$\underline{Na_2SO_4}$, Fusion (Est.)	− 3	− 28	− 50
$\underline{Na_2SO_4} + SiO_2 \rightarrow Na_2SiO_3 + SO_3$	− 63	−440	−792
$\underline{Na_2SO_4} + C + SiO_2 \rightarrow Na_2SiO_3 + SO_2 + CO$	− 15	−105	−189
$\underline{BaO} + SiO_2 \rightarrow BaSiO_3$ (Glass)	+ 22	+144	+259

Source: Calculations from values in International Critical Tables.

bustion products, and numerous other furnace phenomena as well as ordinary stack or chimney draft.

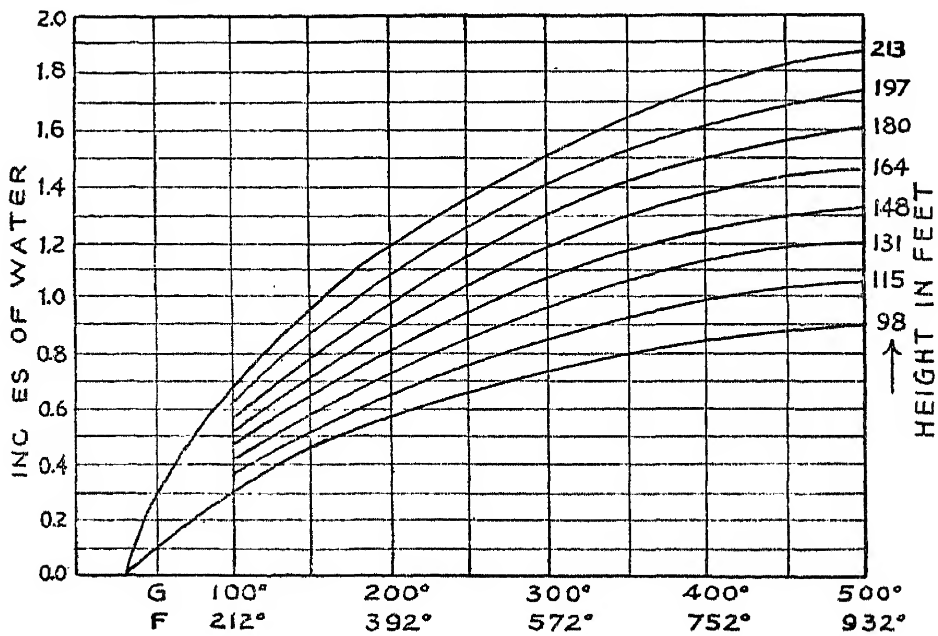
Static draft, or vacuum existing when no gases are moving, can be calculated. Operating draft is less than calculated, because of friction of gases against chimney walls and the relief of vacuum by entering gases. Draft-gage readings slowly increase during half a furnace cycle, as the regenerators become hotter and their opposing draft vacuum builds up.

The formula for calculating static draft, at 30 inches barometer and outside temperature of 80°F., is:

$$h = 0.0120H\left(1.18 - \frac{637}{T_f}\right)$$

where h = draft vacuum in inches water-gage.
H = height of stack in feet.
T_f = temperature of flue gases in °F. above absolute zero; or °F. + 460.

The draft vacuum at the base of a stack throttled to a suitable extent by the stack damper must be sufficient to remove the products of combustion, and to control the entrance of air and fuel gases, and small enough to preserve the slight positive pressure within the furnace. This draft must also overcome the frictional resistance of the outgoing gases as they flow through the ports, checker chambers, valves, and flues. It also overcomes the draft in the reverse direction, set up by the hot checker chambers and uptakes. As a result of these factors, a draft at the stack damper amounting to perhaps 0.5 to 0.6 inch water-gage will be found to fall off steadily, when the flue system and regenerators are explored by portable draft gages, reaching zero somewhere near the top of the uptakes. Within the furnace, under proper firing conditions, positive pressure of perhaps 0.05 inch water-gage exists. Checking by draft gage gives information in furnace control.



STACK DRAFT.

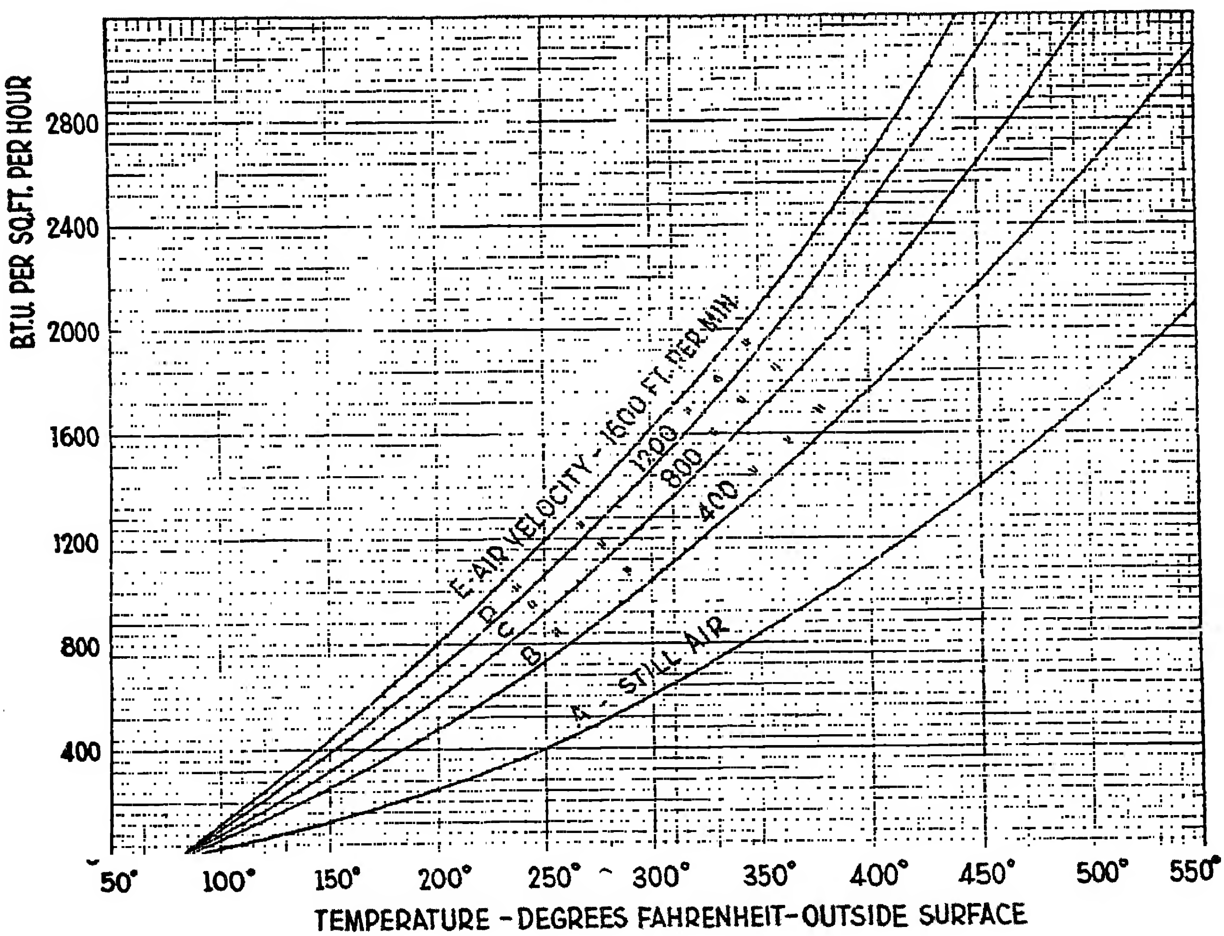
Dimensions

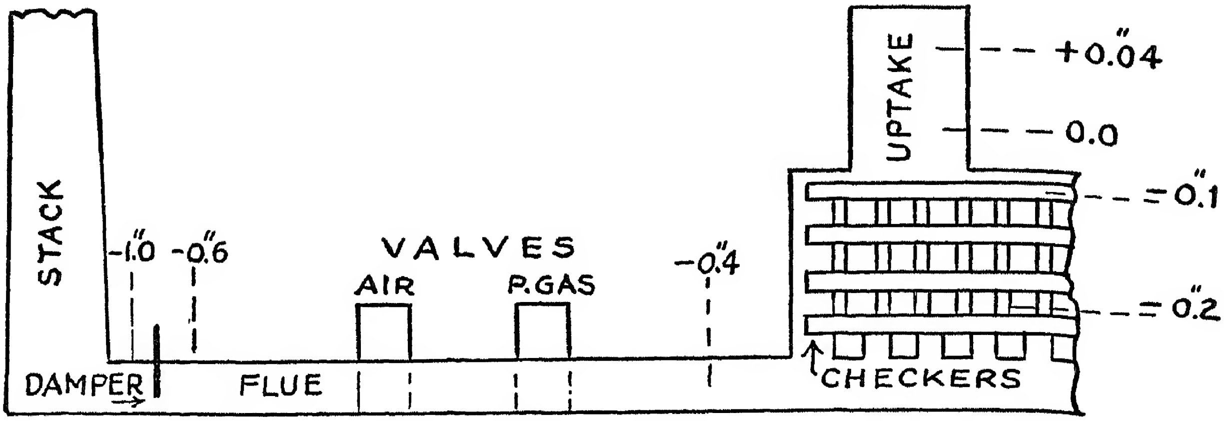
The dimensions of the various chambers and the openings in furnace construction should be based upon the desired velocities for the gases which are to flow through them. A speed of 12 feet per second is usually considered safe for stacks and producer gas mains. Air for combustion should not move faster than 8 feet per second in valves and flues, or 10 feet per second in regenerators and recuperators. The same values hold for flue gases.

The height of the regenerator chambers, which act as stacks to draw in the air and producer gas, depends upon the draft required to give the air or gas sufficient velocity and thus is usually fixed at about 18 feet, including uptakes.

Port areas may be based on an outgoing speed for the flame gases of 25 feet per second. It is obvious that great variation must exist in the quantity of fuel burned per square foot of melting area in tanks having different efficiencies.

Heat Transfer from Surface to Air





CHANGES IN DRAFT VACUUM.

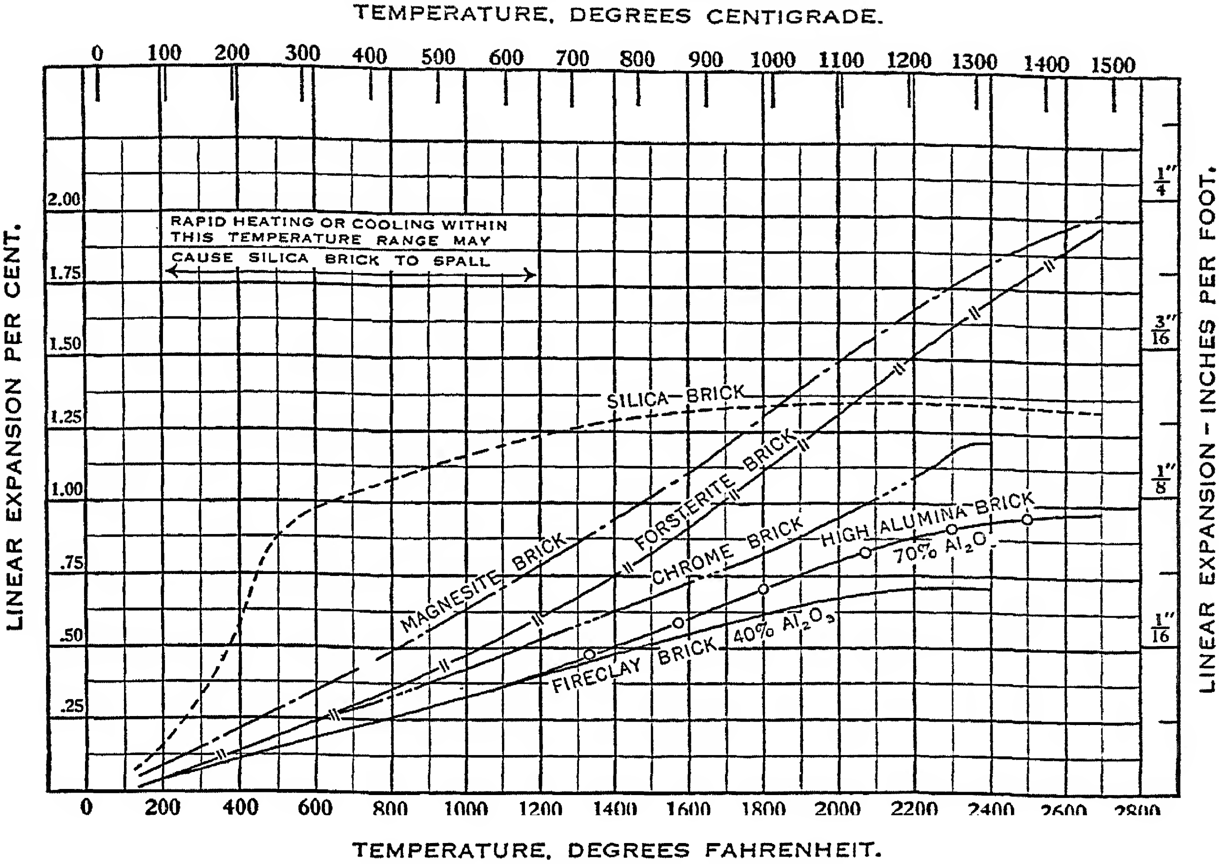
PROPERTIES OF GLASS-FURNACE REFRACTORIES

Material	Bulk Density	Porosity, %	P. C. E.	% Expansion, 0–870°	Coeff. Lin. Exp. per °C., × 10⁶
Dry Press H. H. D. Fire Brick	2.16	16–20	32–33	0.5–0.6	5.6–6.9
Dry Press S. D. Fire Brick	2.32	13–15	33–34	0.5–0.6	5.6–6.9
Vac. Cast Refractory	..	23–25	33–34	...	...
60% Alumina Fire Brick	2.12	25–30	36–37	0.55	6.3
70% Alumina Fire Brick	..	24–27	37–38	...	...
Sillimanite Refractory	..	22–23	35–36	...	...
Clay Flux Block	2.05	18–22	30–32	0.6–0.8	6.9–9.2
Vac. Cast Flux Block	..	15–17	30–31	...	...
Covered Pot (Dry)	1.95	20–25	27–31	...	...

CHEMICAL ANALYSES OF REFRACTORIES

	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	TiO_2	$K_2(Na_2)O$
Int. H. D. Brick	57–60	34–36.5	1–3	0.5–0.8	0–0.5	0.8–1.9	0.7–2.2
H. H. D. Brick	54–57.5	37–40	1–2	0–0.7	0.0.5	1.0–2.0	0.5–1.0
Super H. H. D. Brick	51.5–53.5	42.5–45.0	1–2	0–0.7	0–0.5	1–2	0.5–0.8
60% Alumina Brick	32.5–35.0	59–62	1.3–1.8	0.3–0.7	0–0.3	2.3–3.0	0.5–1.5
70% Alumina Brick	21–25	68–72	1.5–2.3	0.6–1.1	0–0.3	2.5–3.5	1.0–1.7
Vac. Cast Flux Block	67–70	28–25	...	...	...	...	...
Vac. Cast Refractory	50	46	...	...	...	...	...
Sillimanite Refractory	39	58	...	...	...	...	...
Hand-Made Pot	70–73	25–23	...	...	...	...	...
Silica Brick	95–96	...	...	1.8–2.5	...	...	...

Expansibility of Refractories



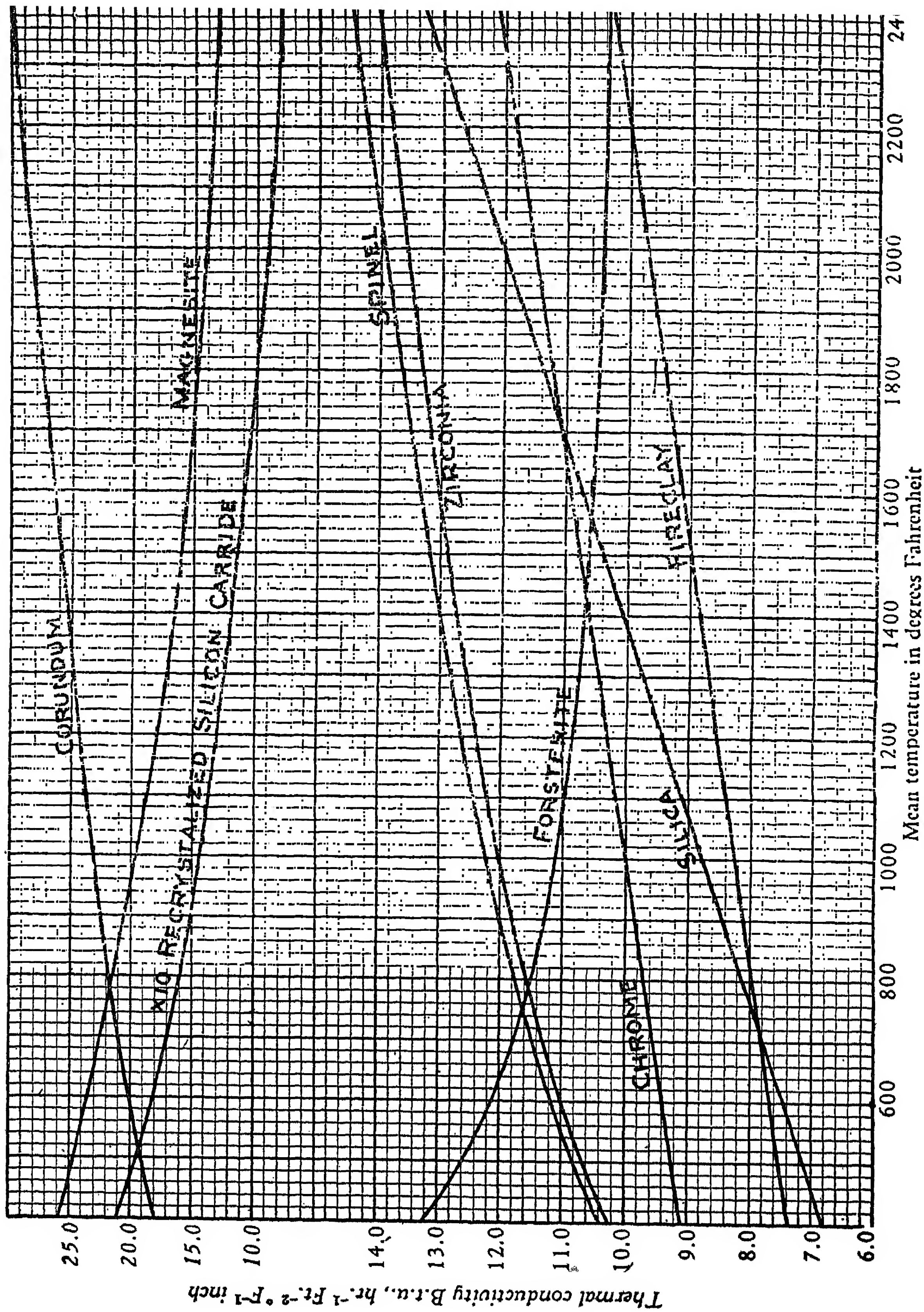
Approximate Reversible Thermal Expansion of Refractories

Linear Per Cent—Mean Values

	Kind of Brick							Kind of Brick					
Temperature, °C.	Silica	Fireclay, 40% Al_2O_3	High-Alumina, 70% Al_2O_3	Magnesite	Chrome	Forsterite	Temperature, °F.	Silica	Fireclay, 40% Al_2O_3	High-Alumina, 70% Al_2O_3	Magnesite	Chrome	Forsterite
100	0.14	0.05	0.05	0.10	0.06	0.05	200	0.13	0.05	0.05	0.09	0.05	0.05
200	0.55	0.11	0.10	0.21	0.14	0.12	400	0.58	0.12	0.10	0.22	0.15	0.12
300	0.95	0.18	0.16	0.33	0.23	0.22	600	0.96	0.19	0.17	0.35	0.24	0.23
400	1.05	0.24	0.22	0.45	0.31	0.32	800	1.07	0.25	0.24	0.48	0.34	0.35
500	1.13	0.31	0.29	0.58	0.40	0.43	1000	1.15	0.33	0.33	0.63	0.43	0.48
600	1.19	0.37	0.36	0.71	0.48	0.55	1200	1.22	0.40	0.40	0.78	0.53	0.61
700	1.24	0.44	0.44	0.86	0.57	0.67	1400	1.26	0.48	0.50	0.95	0.62	0.75
800	1.28	0.50	0.53	1.01	0.66	0.81	1600	1.30	0.55	0.60	1.12	0.72	0.92
							1800	1.32	0.61	0.71	1.31	0.82	1.11
900	1.31	0.57	0.63	1.18	0.75	0.97							
1000	1.32	0.61	0.73	1.34	0.84	1.14	2000	1.33	0.65	0.80	1.49	0.93	1.31
1100	1.33	0.65	0.81	1.50	0.94	1.32	2200	1.33	0.68	0.87	1.68	1.08	1.51
1200	1.33	0.68	0.87	1.67	1.07	1.50	2400	1.33	0.68	0.92	1.83	1.21	1.70
1300	1.33	0.69	0.92	1.80	1.21	1.68	2500	1.33	..	..	..	..	..
1400	1.32	..	0.96	1.94	..	1.85	2600	1.32	..	0.96	1.97	..	1.89
1500	1.30	..	0.98	2.05	..	2.00	2700	1.30	..	0.97	2.03	..	1.98

(Courtesy, Harbison-Walker Refractories Co.)

Thermal Conductivity of Various Refractories



Note change in conductivity values for upper part of chart.

Properties of Finished Refractories

	Brick	Composition	P.C.E. or Softening Point	True Specific Gravity	Approx. Weight 9-In. Brick	Porosity	Linear Coefficient of Expansion	Thermal Conductivity (C.G.S. Units)	Specific Heat	(SiC = 100) Spalling Index	Deformation Under Load (25 Lb./Sq. In.)	Constancy of Volume	Slag Resistance
ACID	High Heat Duty Fire Brick	Al_2O_3: 35–42% SiO_2: 52–60%	31–33 (3056–3173°F.)	2.60–2.70	7.5–8 lb.	15–24%	(21–1300°C.) 0.0000054	(200–1000°C.) 0.00339	(25–1000°C.) 0.254	60–90	3–10% (2462°F.)	0.5 to 2% shrinkage at 2552°F.	Rapidly attacked by basic slags, particularly those high in Fe_2O_3. Moderate resistance to acid slags
	One specific brand of Dry Pressed High Heat Duty Refractory Brick	Al_2O_3: 40.3% SiO_2: 55.0%	33	2.60–2.70	8.2 lb.	18.6%	(21–1300°C.) 0.0000054	(200–1000°C.) 0.00339	(25–1000°C.) 0.254	80–85	2.6% (2462°F.)	0.8% shrinkage at 2552°F.	
	One specific brand of Stiff Mud Repressed High Heat Duty Refractory Brick	Al_2O_3: 39.4% SiO_2: 56.0%	32½	2.60–2.70	8 lb.	16%	(21–1300°C.) 0.0000054	(200–1000°C.) 0.00339	(25–1000°C.) 0.254	75–80	3.5% (2462°F.)	1.2% shrinkage at 2552°F.	
	Super-Duty	Al_2O_3: 43–44% SiO_2: 51–53%	33–34	2.60–2.70	8–8.3 lb.	12–16%	Approx. same as high heat duty fire brick			90–95	1–2% (2462°F.)	1% max. shrinkage at 2900°F.	
	High Alumina	Al_2O_3: 50–60–70 or 80%	34–39 (3200–3389°F.)	2.60–2.70	8–8.3 lb.	20–31%	Approx. same as high heat duty fire brick			60–80	Somewhat less than high heat duty fire brick	Abnormally high shrinkage of most brands in continued service above 2550°F.	More resistant to most alkalies than fire brick. Readily attacked by Fe_2O_3
	Kaolin	Al_2O_3: 44–45% SiO_2: 51–53%	31–34 (3056–3200°F.)	2.60–2.70	8–8.3 lb.	18–28%	(21–1610°C.) 0.0000043	(200–1000°C.) 0.0045	(250–1000°C.) 0.254	75–85	1.0% at 2800°F.	0.5% shrinkage at 3000°F.	Approx. same as high heat-duty fire brick. Slightly better resistance to alkalies
	Converted Kyanite (Sillimanite)	Al_2O_3: 60% SiO_2: 36%	38 (3335°F.)	3.00	8.4 lb.	16–24%	(200–1600°C.) 0.0000045	(600–900°C.) 0.0044	(20–800°C.) 0.175	90	0.0% at 2462°F. 1.0% at 2900°F.	No shrinkage at 3000°F. 2.5% at 3200°F.	Relatively insoluble in most slags and glasses, particularly those high in lime, alkalies, or fluorides. Attacked by strongly basic slags or those high in Fe_2O_3
	Molten Cast Mullite	Al_2O_3: 71–72%	38 (3335°F.)	3.00	10–10.25 lb.	0.5–1%	(21–900°C.) 0.0000060	0.0060 (No temperature range given)	(21–980°C.) 0.25	50–60	No deformation at 1350°C.	No appreciable change at 1593–1649°C.	Chem. characteristics of mullite; low porosity and high density. Offer maximum resistance to corrosion
	Zircon	$ZrO_2 \cdot SiO_2$	Above 2550°C. 4622°F.	4.6	12 lb.	20–26%	(21–1550°C.) 0.0000042	(200–1000°C.) 0.0046	.....	70–90	Failed at 1550–1600°C.	No appreciable change at 1550°C.	Slightly attacked by acid slags. Strongly attacked by basic slags and fluorides
	Silica	SiO_2: 95–96%	31–33 (3056–3173°F.)	2.30–2.40	6 lb.	22–30%	(21–1550°C.) 0.0000083	(200–1000°C.) 0.0045	(25–1000°C.) 0.265	10–30	0.0% at 1500°C. (50 lb./sq. in.)	Reversible expansion to 3173°F. No shrinkage	Resists acid slags and dust. Attacked by basic slags, fluorides and Fe_2O_3
	Recrystallized Silicon Carbide	SiC: 98–99%	Dissociates at 2250°C. 4082°F.	3.17	9 lb.	20%	(21–1000°C.) 0.0000045	(200–1350°C.) 0.0330	(21–800°C.) 0.225	100	0.0% at 1500°C. (50 lb./sq. in.)	No shrinkage at 1500°C.; up to 10% perm. expansion due to oxidation	Attacked by basic slags, particularly those high in iron oxide
NEUTRAL	Fused Alumina	Al_2O_3: 88–90%	2050°C. 3722°F.	3.90	11 lb.	21%	(21–800°C.) 0.0000081	(200–1000°C.) 0.0095	(20–800°C.) 0.272	60–70	2% at 1500°C. (50 lb./sq. in.)	No shrinkage at 1500°C.	Similar properties to P. B. sillimanite
	Chrome	Cr_2O_3: 30–45% Al_2O_3: 15–33% SiO_2: 11–17% FeO: 3–6%	1950–2200°C. 3542–3992°F.	3.80–4.10	11 lb.	20–28%	(21–1540°C.) 0.0000104	(200–1000°C.) 0.0040	(21–1000°C.) 0.217	25–70	Improved chrome brick show no deformation at 1425°C.	No shrinkage at 1450°C. 1.3% at 1550°C.	Neutral properties, resistant to both acid and basic slags
BASIC	Magnesite (Burned)	MgO: 83–93% Fe_2O_3: 2–7%	2200°C. 3992°F.	3.40–3.60	9.5 lb.	20–28%	(21–1700°C.) 0.0000147	(200–1000°C.) 0.0087	(21–1000°C.) 0.278	20–40	Not recommended where high hot strength req'd	Shrinkage at temp. above 1600°C.	Highly resistant to basic slags. Readily attacked by acid slags
	Magnesite (Unburned)	MgO: 83–93% Fe_2O_3: 2–7%	2200°C. 3992°F.	3.40–3.60	10.5 lb.	10–22%	.....	.....	(21–1000°C.) 0.278	30–50	3.5% deformation at 1480°C.	Some shrinkage at 1500°C. 2.6% at 1550°C.	
	Forsterite	$2MgO \cdot SiO_2$	1910°C. 3470°F.	3.30–3.40	9 lb.	24–27%	(21–1500°C.) 0.0000125	Slightly lower than magnesite	.....	20–40	Similar to silica	Negligible shrinkage on reheat to 1650°C.	Similar to magnesite, but more readily attacked by either acid or basic slags

References: "Modern Refractory Practice," 2nd Edition, Harbison-Walker Refractories Company.
"Industrial Furnaces," 3rd Edition, Trinks.
"Refractories," Norton.
"Zircon Refractories," Comstock.
"Norton Heavy Duty Refractories," The Norton Co.

Note: To change C. G. S. units to B.t.u. per sq. ft. per 1°F. per inch thickness, multiply by 2903.

COURTESY
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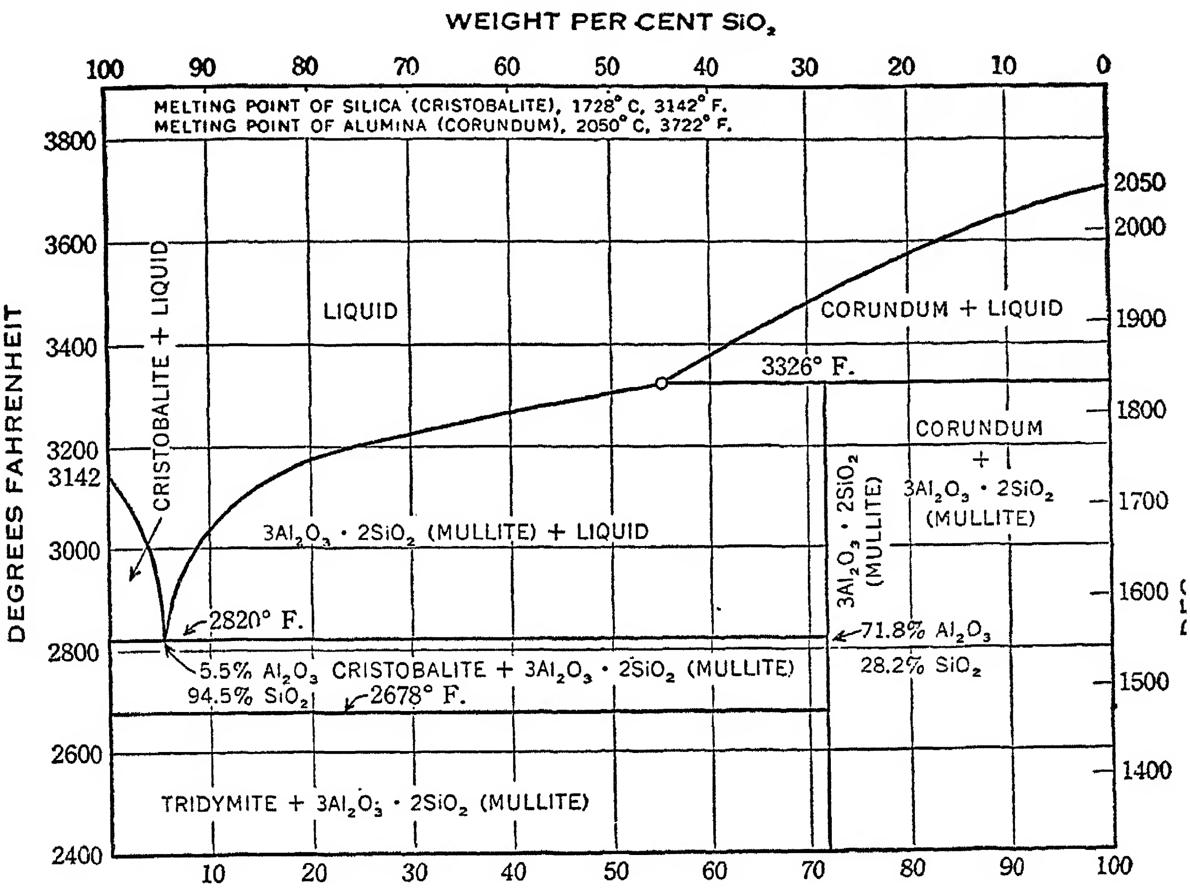


EQUILIBRIUM DIAGRAM OF THE SYSTEM $Al_2O_3 - SiO_2$ (BOWEN & GRIEG)

This diagram describes the behavior of mixtures containing alumina and silica, only. It brings out the following important facts:

A small addition of alumina lowers the melting point of silica very rapidly; hence clay is a poor mortar for silica brick, and clay brick should never be laid upon silica brick in a furnace wall. Any mixture of alumina and silica, containing less than 71.8% Al_2O_3, forms some liquid of the eutectic composition (5.5% Al_2O_3) at 2820°F. If impurities are present, and this is true for all clays, the temperature at which liquid forms is lowered to an extent depending upon the nature and amount of impurities. Mullite, the only compound of alumina and silica stable at high temperatures, melts at 3326°F., incongruently. That is, it decomposes upon melting, forming corundum and a liquid containing about 45% Al_2O_3. A melt of the mullite composition first forms corundum crystals as it cools, and the remaining liquid then forms a larger quantity of mullite crystals, and the residual silica forms a small amount of glass with the impurities usually present.

As in any silicate system, equilibrium is reached very slowly at temperatures beneath the liquidus curve.

Section VIII

PYROMETERS

Pyrometers

Instruments

Recording and Indicating Pyrometers

THE types of pyrometers most in use in the glass industry are thermocouple, radiation, and optical. The thermocouple consists of a pair of dissimilar wires welded at one end and suitably connected to an instrument capable of indicating E.M.F., at the opposite or cold end. Base-metal couples may be chromel-alumel, iron-constantan, or other pairs. They have the advantage of generating a relatively large electromotive force amounting to about four millivolts per 100°C. difference between hot and cold ends. Their use is limited to temperatures below the rapid oxidation temperatures of the metals; that is, below approximately 1200°C. They are valuable for annealing lehrs. The noble-metal couples are commonly made of platinum and an alloy of platinum with 10 per cent of rhodium, and generate an E.M.F. of approximately one millivolt per 100°C. temperature difference. Thermocouples are usually enclosed in protecting tubes to prevent contamination or alteration of the wires by furnace gases, molten glass, or other foreign substances. In lehrs, where temperatures and corrosive conditions are not severe, ordinary wrought iron is quite satisfactory. Chrome-iron alloys are better in checker chambers. In a furnace crown, or side wall, where temperatures are very high, the best protection is offered by ceramic tubes. For thermocouples to be immersed directly in the molten glass, a pure platinum tube is used because this is practically the only material which will at once protect the couple and not contaminate or discolor the glass.

The E.M.F. generated by the thermocouples may be indicated on a galvanometer calibrated to read directly in degrees. This type of instrument is subject to errors arising from the resistance of the thermocouple and its lead wires, and has now largely been replaced by the potentiometer type, in which the thermocouple voltage is balanced against the voltage of a dry cell standardized against a standard cell.

When the thermocouple wires cannot be carried directly to the instrument, as is usually the case, compensating lead wires are used whose contacts with the ends of the thermocouple wires (the temperature of which is usually higher than that of the instrument) serves to generate such an electromotive force as will restore the E.M.F. delivered to the instrument to its true value.

Thermocouple installations are subject to the following difficulties: (1) The voltage is a feeble one, and connections must be firm; (2) the

protection tube may be so thick or so deeply embedded in the wall of the furnace as to indicate a temperature much lower than the actual furnace temperature; (3) the thermocouple can indicate only the difference in temperature between its hot and cold junctions, and both the proper installation of compensating lead wires and proper attention to instrument temperatures become important; (4) the slow crystallization of noble-metal couples results in their gradual deterioration and they should be checked at intervals of six months at most.

Recording Pyrometers

When indicating instruments are supplied with registering devices and clocks for moving a suitable blank under the registering pen, they become recording instruments and supply a curve which is a graph of temperature against time. These, or indicating instruments, may also be connected through relays with electrical devices which will operate switches or valves and thus control furnace temperature within narrow limits.

Checking Instruments

The calibrations of thermocouples from reliable manufacturers can usually be depended upon until after extended use. They can be checked against certain accepted standards obtained by making use of the melting and boiling of certain substances, and these temperatures will be found in appropriate tables. Needless to say, the instruments are subject to rapid deterioration from shocks, excessive room temperatures, or dusts and fumes.

Radiation Pyrometers

Radiation pyrometers are, in effect, telescopes which focus the heat of a furnace upon a delicate compound thermocouple, whose E.M.F. may then be indicated or recorded as above. These form convenient portable types.

Optical Pyrometers

Optical pyrometers indicate temperature by matching the luminosity of the furnace against that of some variable standard. A favorite form makes use of an incandescent filament heated by a variable current whose amperage corresponds to the temperature of the furnace when the filament is just hot enough to disappear against the furnace background. Filters of colored glass absorb a part of the radiant light, bringing it down to an intensity tolerable for the eye. These instruments are useful for checking the indications of thermocouple instruments and for reading temperatures at points inaccessible to thermocouples.

Thermometers

Thermometers capable of making temperature indications and records at a distance are particularly useful for controlling the temperature of the blast for gas producers. They are not suitable for higher temperatures such as those encountered in lehrs, producers, or furnaces.

E.M.F. Values for Chromel-Alumel Thermo-Elements

Centigrade Temperature

Degrees C.	Millivolts									
	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°
0	0	0.41	0.82	1.23	1.65	2.07	2.48	2.90	3.32	3.73
100	4.15	4.56	4.98	5.39	5.79	6.19	6.59	6.99	7.39	7.79
200	8.19	8.60	9.00	9.41	9.82	10.23	10.64	11.05	11.46	11.87
300	12.29	12.70	13.12	13.54	13.96	14.38	14.79	15.21	15.63	16.06
400	16.48	16.91	17.33	17.75	18.18	18.60	19.03	19.45	19.88	20.31
500	20.74	21.17	21.59	22.02	22.44	22.87	23.30	23.73	24.15	24.58
600	25.00	25.42	25.85	26.27	26.69	27.12	27.55	27.96	28.37	28.79
700	29.21	29.62	30.03	30.44	30.85	31.26	31.66	32.07	32.47	32.88
800	33.28	33.68	34.08	34.48	34.88	35.27	35.66	36.06	36.46	36.85
900	37.25	37.64	38.04	38.43	38.82	39.21	39.60	39.98	40.37	40.81
1000	41.13	41.51	41.89	42.26	42.64	43.01	43.38	43.75	44.12	44.48
1100	44.85	45.21	45.57	45.93	46.29	46.65	47.01	47.36	47.71	48.07

Fahrenheit Temperature

Degrees F.	Millivolts									
	+0°	10°	20°	30°	40°	50°	60°	70°	80°	90°
0	...	...	...	...	0.16	0.40	0.63	0.87	1.10	1.34
100	1.57	1.80	2.03	2.26	2.49	2.72	2.94	3.17	3.40	3.63
200	3.85	4.08	4.31	4.54	4.77	5.00	5.23	5.46	5.69	5.92
300	6.15	6.37	6.59	6.81	7.03	7.25	7.47	7.69	7.91	8.13
400	8.35	8.57	8.80	9.03	9.26	9.49	9.72	9.95	0.18	10.31
500	10.64	10.87	11.10	11.33	11.56	11.79	12.02	12.25	12.48	12.71
600	12.95	13.18	13.41	13.64	13.87	14.10	14.34	14.56	14.79	15.02
700	15.25	15.48	15.71	15.95	16.19	16.43	16.67	16.91	17.15	17.39
800	17.63	17.87	18.10	18.33	18.56	18.79	19.03	19.26	19.49	19.72
900	19.96	20.20	20.44	20.68	20.92	21.16	21.40	21.64	21.88	22.12
1000	22.36	22.60	22.83	23.07	23.30	23.54	23.77	24.01	24.24	24.47
1100	24.70	24.93	25.17	25.41	25.65	25.89	26.13	25.36	25.60	25.84
1200	27.08	27.31	27.54	27.77	28.00	28.22	28.45	28.68	28.91	29.14
1300	29.37	29.60	29.83	30.06	30.29	30.52	30.75	30.97	31.20	31.43
1400	31.66	31.88	32.11	32.34	32.56	32.78	33.00	33.23	33.46	33.69
1500	33.92	34.14	34.36	34.58	34.80	35.02	35.23	35.45	36.67	35.89
1600	36.10	36.32	36.54	36.76	36.98	37.20	37.42	37.65	37.88	38.11
1700	38.33	38.54	38.75	38.96	39.17	39.38	39.60	39.81	40.02	40.23
1800	40.45	40.66	40.87	41.08	41.29	41.51	41.73	41.94	42.15	42.39
1900	42.58	42.78	42.98	43.18	43.38	43.58	43.79	43.99	44.19	45.39
2000	44.59	44.79	45.00	45.20	45.41	45.61	45.82	46.02	46.22	46.42

E.M.F. Values for Pt–Pt–Rh (10%) Thermo-Elements

Centigrade Temperature

Degrees C.	Millivolts 0°	10°	20°	30°	40°	50°	60°	70°	80°	90°
0	0	0.06	0.11	0.17	0.24	0.30	0.36	0.43	0.50	0.57
100	0.64	0.72	0.79	0.87	0.95	1.02	1.10	1.18	1.26	1.35
200	1.43	1.52	1.60	1.69	1.78	1.86	1.95	2.04	2.13	2.22
300	2.31	2.40	2.50	2.59	2.68	2.77	2.87	2.96	3.05	3.15
400	3.24	3.34	3.44	3.53	3.63	3.73	3.82	3.92	4.02	4.12
500	4.22	4.31	4.41	4.51	4.61	4.71	4.82	4.92	5.02	5.12
600	5.22	5.32	5.43	5.53	5.63	5.74	5.84	5.94	6.05	6.16
700	6.26	6.37	6.47	6.58	6.68	6.79	6.89	7.01	7.11	7.22
800	7.33	7.44	7.55	7.66	7.77	7.88	7.99	8.10	8.21	8.32
900	8.43	8.54	8.66	8.77	8.89	9.00	9.11	9.22	9.34	9.46
1000	9.57	9.68	9.80	9.92	10.03	10.15	10.27	10.38	10.50	10.62
1100	10.74	10.86	10.98	11.10	11.21	11.33	11.45	11.57	11.69	11.81
1200	11.93	12.05	12.17	12.29	12.41	12.53	12.65	12.77	12.89	13.01
1300	13.13	13.25	13.37	13.49	13.61	13.73	13.85	13.97	14.09	14.21
1400	14.33	14.45	14.58	14.70	14.82	14.94	15.06	15.19	15.31	15.43
1500	15.55	15.67	15.79	15.91	16.03	16.15	16.27	16.39	16.51	16.63

Fahrenheit Temperature

Degrees F.	Millivolts +0°	10°	20°	30°	40°	50°	60°	70°	80°	90°
0	...	...	...	...	0.02	0.05	0.09	0.12	0.15	0.19
100	0.22	0.26	0.29	0.33	0.37	0.40	0.44	0.48	0.52	0.55
200	0.59	0.63	0.68	0.72	0.76	0.80	0.84	0.89	0.93	0.97
300	1.02	1.06	1.11	1.15	1.20	1.24	1.29	1.33	1.38	1.43
400	1.48	1.52	1.57	1.61	1.66	1.71	1.76	1.81	1.86	1.91
500	1.96	2.00	2.05	2.10	2.15	2.20	2.25	2.30	2.36	2.41
600	2.46	2.51	2.56	2.61	2.66	2.71	2.77	2.82	2.87	2.92
700	2.97	3.03	3.08	3.13	3.19	3.24	3.29	3.35	3.40	3.45
800	3.51	3.56	3.61	3.67	3.72	3.77	3.83	3.88	3.94	3.99
900	4.04	4.10	4.15	4.21	4.26	4.32	4.37	4.43	4.48	4.54
1000	4.59	4.65	4.71	4.76	4.82	4.87	4.93	4.99	5.04	5.10
1100	5.15	5.21	5.27	5.32	5.38	5.44	5.49	5.55	5.61	5.67
1200	5.72	5.78	5.84	5.90	5.96	6.01	6.07	6.13	6.19	6.25
1300	6.31	6.37	6.42	6.48	6.54	6.60	6.66	6.72	6.78	6.84
1400	6.90	6.96	7.02	7.08	7.14	7.20	7.26	7.32	7.38	7.44
1500	7.50	7.56	7.62	7.68	7.74	7.80	7.86	7.93	7.99	8.05
1600	8.11	8.17	8.24	8.30	8.36	8.42	8.48	8.55	8.61	8.67
1700	8.73	8.80	8.86	8.92	8.99	9.05	9.11	9.17	9.24	9.30
1800	9.36	9.43	9.49	9.56	9.62	9.69	9.75	9.82	9.88	9.94
1900	10.01	10.07	10.14	10.20	10.27	10.33	10.40	10.46	10.53	10.59
2000	10.66	10.72	10.79	10.85	10.92	10.99	11.05	11.12	11.18	11.25
2100	11.32	11.38	11.45	11.51	11.58	11.65	11.71	11.78	11.84	11.91
2200	11.98	12.04	12.11	12.18	12.24	12.31	12.38	12.44	12.51	12.57
2300	12.64	12.71	12.77	12.84	12.91	12.97	13.04	13.11	13.17	13.24
2400	13.31	13.37	13.44	13.51	13.57	13.64	13.70	13.77	13.84	13.90
2500	13.97	14.03	14.10	14.17	14.23	14.30	14.37	14.43	14.50	14.56
2600	14.63	14.69	14.76	14.83	14.89	14.96	15.02	15.09	15.16	15.22
2700	15.29	15.35	15.42	15.48	15.55	15.61	15.68	15.75	15.81	15.88
2800	15.94	16.01	16.07	16.14	16.21	16.27	16.33	16.40	16.47	16.53

E.M.F. VALUES FOR PT–PT–RH (13%) THERMO-ELEMENTS

CENTIGRADE TEMPERATURE

Degrees C.	Millivolts									
	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°
0	0	0.06	0.12	0.18	0.25	0.31	0.38	0.45	0.52	0.60
100	0.67	0.75	0.83	0.90	0.99	1.07	1.15	1.23	1.32	1.40
200	1.49	1.58	1.67	1.76	1.85	1.94	2.03	2.12	2.21	2.30
300	2.40	2.49	2.59	2.68	2.77	2.87	2.98	3.08	3.19	3.29
400	3.40	3.51	3.61	3.72	3.82	3.93	4.04	4.15	4.25	4.36
500	4.47	4.58	4.69	4.81	4.92	5.03	5.14	5.26	5.37	5.49
600	5.60	5.72	5.83	5.95	6.06	6.18	6.30	6.42	6.53	6.65
700	6.77	6.89	7.01	7.13	7.25	7.37	7.49	7.62	7.74	7.87
800	7.99	8.12	8.24	8.37	8.49	8.62	8.75	8.88	9.00	9.13
900	9.26	9.39	9.52	9.66	9.79	9.92	10.05	10.18	10.32	10.45
1000	10.58	10.72	10.85	10.99	11.12	11.26	11.40	11.54	11.67	11.81
1100	11.95	12.09	12.23	12.38	12.52	12.66	12.80	12.94	13.09	13.23
1200	13.37	13.52	13.66	13.82	13.95	14.10	14.25	14.40	14.54	14.69
1300	14.84	14.99	15.14	15.30	15.45	15.60	15.75	15.90	16.06	16.21
1400	16.36	16.52	16.67	16.83	16.98	17.14	17.30	17.46	17.61	17.77
1500	17.93	18.09	18.25	18.42	18.58	18.74	18.90	19.06	19.23	19.39

FAHRENHEIT TEMPERATURE

Degrees F.	Millivolts									
	+0°	10°	20°	30°	40°	50°	60°	70°	80°	90°
0	...	...	...	...	0.03	0.06	0.10	0.14	0.18	0.21
100	0.24	0.28	0.32	0.36	0.39	0.43	0.47	0.51	0.54	0.58
200	0.62	0.66	0.71	0.75	0.79	0.83	0.88	0.92	0.97	1.01
300	1.06	1.11	1.15	1.20	1.25	1.29	1.34	1.38	1.43	1.48
400	1.53	1.58	1.63	1.68	1.73	1.78	1.83	1.88	1.93	1.98
500	2.03	2.08	2.13	2.18	2.23	2.28	2.33	2.38	2.44	2.49
600	2.55	2.60	2.65	2.71	2.76	2.81	2.86	2.92	2.97	3.03
700	3.09	3.15	3.21	3.26	3.32	3.38	3.44	3.50	3.56	3.62
800	3.68	3.74	3.80	3.86	3.92	3.98	4.04	4.10	4.15	4.21
900	4.27	4.33	4.40	4.46	4.52	4.59	4.65	4.71	4.77	4.84
1000	4.90	4.96	5.02	5.09	5.15	5.21	5.27	5.33	5.40	5.46
1100	5.53	5.59	5.65	5.72	5.78	5.84	5.91	5.97	6.04	6.10
1200	6.17	6.23	6.29	6.35	6.42	6.48	6.55	6.62	6.69	6.75
1300	6.82	6.89	6.96	7.02	7.09	7.16	7.23	7.29	7.36	7.42
1400	7.49	7.56	7.63	7.70	7.77	7.84	7.91	7.97	8.04	8.10
1500	8.17	8.24	8.32	8.39	8.46	8.53	8.60	8.67	8.74	8.81
1600	8.89	8.96	9.03	9.10	9.17	9.24	9.31	9.39	9.46	9.84
1700	9.62	9.69	9.76	9.83	9.91	9.98	10.05	10.12	10.20	10.27
1800	10.35	10.42	10.50	10.57	10.65	10.72	10.80	10.87	10.95	11.02
1900	11.10	11.17	11.25	11.32	11.40	11.47	11.55	11.62	11.70	11.77
2000	11.85	11.93	12.01	12.09	12.17	12.25	12.33	12.41	12.49	12.57
2100	12.65	12.73	12.81	12.89	12.96	13.04	13.12	13.19	13.27	13.35
2200	13.43	13.51	13.59	13.67	13.75	13.83	13.92	14.00	14.08	14.17
2300	14.25	14.33	14.41	14.49	14.57	14.65	14.74	14.82	14.91	15.00
2400	15.08	15.16	15.24	15.33	15.41	15.49	15.58	15.66	15.75	15.83
2500	15.91	16.00	16.08	16.17	16.25	16.34	16.42	16.51	16.60	16.68
2600	16.77	16.85	16.94	17.03	17.12	17.21	17.30	17.39	17.48	17.57
2700	17.65	17.74	17.83	17.92	18.00	18.08	18.18	18.27	18.36	18.45
2800	18.54	18.63	18.72	18.81	18.90	18.99	19.08	19.17	19.26	19.35

E.M.F. Values for Iron-Constantan Thermo-Elements

Centigrade Temperature

Degrees C.	E.M.F.	Degrees C.	E.M.F.	Degrees C.	E.M.F.
0	0	500	27.41	1000	58.17
50	2.61	550	30.24	1050	61.33
100	5.28	600	33.13	1100	64.50
150	8.01	650	36.11	1150	67.67
200	10.77	700	39.19	1200	70.84
250	13.54	750	42.33	...	...
300	16.30	800	45.49	...	...
350	19.06	850	48.66	...	...
400	21.83	900	51.83	...	...
450	24.61	950	55.00	...	...

Fahrenheit Temperature

	Millivolts									
Degrees F.	+0°	10°	20°	30°	40°	50°	60°	70°	80°	90°
0	...	...	...	...	0.23	0.52	0.81	1.10	1.39	1.68
100	1.97	2.26	2.56	2.86	3.15	3.45	3.74	4.04	4.33	4.63
200	4.93	5.23	5.53	5.83	6.13	6.43	6.74	7.04	7.35	7.65
300	7.96	8.26	8.57	8.88	9.18	9.49	9.80	10.11	10.41	10.72
400	11.03	11.34	11.64	11.95	12.26	12.56	12.87	13.18	13.49	13.80
500	14.11	14.42	14.72	15.03	15.33	15.64	15.94	16.25	16.56	16.86
600	17.17	17.48	17.78	18.09	18.40	18.70	19.01	19.32	19.63	19.93
700	20.24	20.55	20.85	21.16	21.47	21.77	22.08	22.39	22.70	23.01
800	23.32	23.63	23.94	24.25	24.56	24.87	25.18	25.49	25.80	26.11
900	26.42	26.73	27.04	27.36	27.67	27.98	28.30	28.61	28.92	29.24
1000	29.56	29.87	30.19	30.51	30.83	31.15	31.47	31.79	32.11	32.43
1100	32.75	33.08	33.41	33.74	34.08	34.41	34.74	35.07	35.40	35.73
1200	36.06	36.40	36.74	37.08	37.43	37.77	38.11	38.45	38.79	39.14
1300	39.49	39.84	40.19	40.54	40.88	41.23	41.58	41.93	42.28	42.63
1400	42.98	43.33	43.68	44.03	44.38	44.73	45.08	45.44	45.80	46.15
1500	46.50	46.85	47.20	47.56	47.91	48.26	48.61	48.97	49.32	49.67
1600	50.03	50.38	50.73	51.08	51.43	51.78	52.14	52.49	52.84	53.19
1700	53.55	53.90	54.25	54.60	54.95	55.30	55.66	56.01	56.36	56.71
1800	57.07	57.42	57.77	58.12	58.47	58.82	59.17	59.52	59.87	60.22
1900	60.57	60.92	61.28	61.63	61.98	62.33	62.68	63.04	63.39	63.74
2000	64.09	64.45	64.80	65.15	65.50	65.85	66.20	66.55	66.90	67.25

Interchanged Thermocouples and Instruments

The usual indicating pyrometer is really a millivoltmeter calibrated directly in degrees for a particular type of thermocouple. A certain temperature will cause a chromel-alumel couple to generate about four times as much E.M.F. as a Pt-Pt-Rh couple at the same temperature.

If, for any reason, a "C-A" couple is used on an instrument intended for a platinum-platinum-rhodium couple, the temperature indication will be about four times too high and vice versa.

Accurate corrections for readings from these misfit combinations may be made as follows: (1) Find from the proper table the m. v. corresponding to the temperature indicated, for the type of couple intended for the instrument. (2) Find from the other table the temperature corresponding to this millivoltage for the couple which is actually used.

Corrections for a number of temperatures are shown in the accompanying table.

Temp. for C-A Thermocouple		E.M.F.	Temp. for Pt-Pt-10% Rh Thermocouples	
°C.	°F.	M. v.	°C.	°F.
12	54	0.5	80	176
22	72	1.0	147	296
37	99	1.5	208	407
50	122	2.0	266	510
60	140	2.5	320	608
72	162	3.0	375	707
85	185	3.5	427	800
97	207	4.0	478	892
109	229	4.5	529	984
121	250	5.0	578	1073
133	271	5.5	627	1160
146	295	6.0	675	1247
158	316	6.5	723	1333
170	338	7.0	769	1416
183	362	7.5	815	1499
196	385	8.0	861	1582
208	406	8.5	906	1663
220	428	9.0	950	1742
232	450	9.5	994	1822
244	471	10.0	1037	1898
257	494	10.5	1080	1976
269	516	11.0	1122	2052
281	538	11.5	1164	2127
293	560	12.0	1206	2203
305	581	12.5	1248	2278
317	602	13.0	1289	2352
329	624	13.5	1331	2428
341	646	14.0	1373	2504
353	668	14.5	1414	2577
365	689	15.0	1455	2651
377	711	15.5	1496	2725
389	733	16.0	1537	2800

End Point, Bending Interval, and Cone Interval of Orton Cones

Cone No.	End Point				Bending Interval		Cone Interval	
	Rate 20 °C./Hr.		Rate 150 °C./Hr.		20 °C.	150 °C.	20 °C.	150 °C.
013	1517 °F.	825 °C.	860 °C.		45 °C.	50 °C.	15 °C.	15 °C.
012	1544	840	825		50	85	35	30
011	1607	875	905		65	65	15	10
010	1634	890	895		30	25	40	35
09	1706	930	930		35	40	15	20
08	1733	945	950		55	60	30	40
07	1787	975	990		35	50	30	25
06	1841	1005	1015		25	35	25	25
05	1886	1030	1040		30	30	20	20
04	1922	1050	1060		40	40	30	55
03	1976	1080	1115		40	35	15	10
02	2003	1095	1125		35	35	15	20
01	2030	1110	1145		50	45	15	15
1	2057	1125	1160		30	45	10	5
2	2075	1135	1165		30	45	10	5
3	2093	1145	1170		30	40	20	20
4	2129	1165	1190		40	35	15	15
5	2156	1180	1205		40	50	10	25
6	2174	1190	1230		40	35	20	20
7	2210	1210	1250		40	60	15	10
8	2237	1225	1260		45	55	25	25
9	2282	1250	1285		65	115	10	20
10	2300	1260	1305		40	95	25	20
11	2345	1285	1325		70	80	25	10
12	2390	1310	1335		80	45	40	15
13	2462	1350	1350		70	55	40	50
14	2534	1390	1400		100	70	20	35
15	2570	1410	1435		85	115	40	30
16	2642	1450	1465		70	125	15	10
17	2669	1465	1475		50–75	125	20	15
18	2705	1485	1490		90	85	30	30
19	2759	1515	1520		100	70	5	10
20	2768	1520	1530		...	60	..	50
23	....	....	1580	(2876 °F.)	Cones	30	..	15
26	....	....	1595	(2903 °F.)	23 to 38	10	..	10
27	....	....	1605	(2921 °F.)	heated	15	..	10
28	....	....	1615	(2939 °F.)	at	10	..	25
29	....	....	1640	(2984 °F.)	100 °C.	30	..	10
30	....	....	1650	(3002 °F.)	...	25	..	30
31	....	....	1680	(3056 °F.)	...	25	..	20
32	....	....	1700	(3092 °F.)	...	15	..	45
33	....	....	1745	(3173 °F.)	...	30	..	15
34	3191	1755	1760	(3200 °F.)	...	15	..	25
35	3227	1775	1785	(3245 °F.)	...	15	..	25
36	3290	1810	1810	(3290 °F.)	...	25	..	10
37	3326	1830	1820	(3308 °F.)	...	5	..	15
38	3362	1850	1835		...	15	..	..
39	3389	1865	....		...	...	..	..
40	3425	1885	....		...	...	..	..
41	3578	1970	....		...	...	..	..

Section IX

WARE DEFECTS

Ware Defects

Machine Blown Ware

HERE is presented in considerable detail a list of ware defects, with the common causes for such defects. This list does not include all types of defects nor all causes for defects, but represents those most commonly encountered.

No attempt has been made to list the numerous ware defects and causes which are due to the mechanical operation and condition of the forming machine. The defects listed deal more specifically with the condition of the glass, the molds, and alignment.

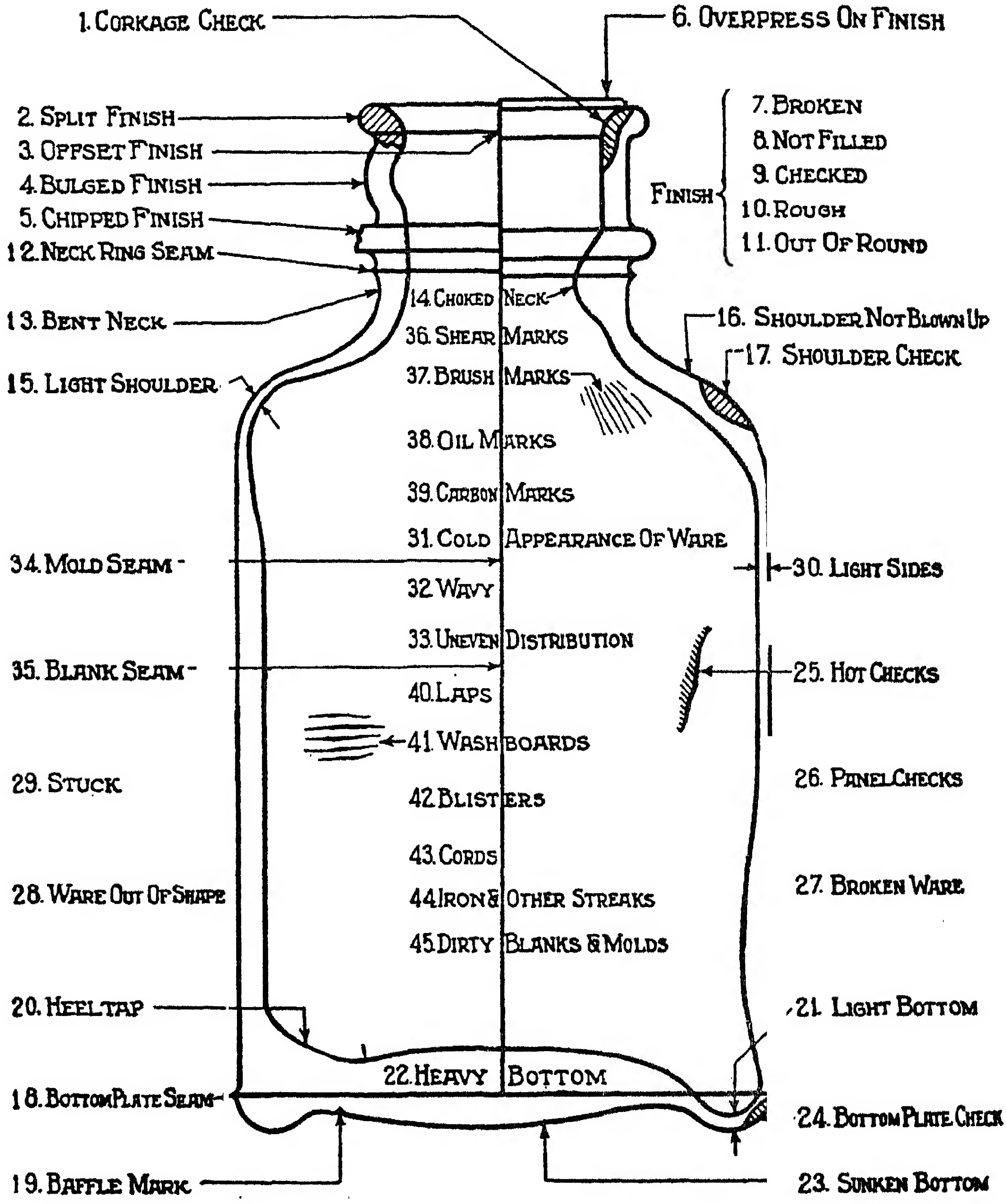
There is no accepted terminology for defects, but the adjacent diagram shows those names which are commonly used in the trade. The index numbers shown on the diagram correspond with the paragraph numbers below, thus facilitating cross reference.

Correction of Machine-Blown Ware Faults

1. Corkage Checks
   - Glass too cold
   - Too much settle blow
   - Plunger too cold
   - Plunger contact time too long or too short
2. Split Finishes
   - Cold glass
   - Too much settle blow
   - Plunger too cold or too long
   - Wind over top of blow mold
   - Plunger contact time too long
3. Offset Finishes
   - Dovetail on rings too small
   - Mold size for dovetail too large
   - Carbon on faces of blank halves causing blanks to stand open, resulting in loose rings and large finish seams
4. Bulged Finishes
   - Finishes not set hard enough
   - Not enough settle blow
   - Plunger contact too short
   - Not enough counterblow
   - Blowhead too shallow
5. Chipped Finishes
   - Cold glass
   - Too much settle blow
   - Neck rings opening too fast or too slow
   - Plunger too long
6. Overpress on Finish
   - Plunger diameter too small
   - Plunger match with ring too short
   - Plunger not seating properly
7. Broken Finishes
   - Glass too cold
   - Finish set too hard
   - Plunger contact too long or plunger too long—freezing finishes
   - Mold closing too late
   - Takeout tongs out of alignment
   - Takeout set too high
   - Wind blowing on finishes
8. Finishes Not Filled
   - Glass too cold
   - Glass hanging up in delivery
   - Not enough vent around plunger or in neck ring
   - Not enough settle blow
   - Plunger too long
   - Blanks too hot or too dry—glass hanging up
   - Settle blow too soon
9. Finish Checks
   - Cold glass
   - Plunger adjustment too high or low

Diagram of Machine-Blown Ware Faults

Index numbers on the diagram correspond with paragraph numbers in the text.



From Hartford-Empire Co. Licensee Bulletin No. 15

- Neck rings out of alignment
- Neck rings not relieving
- Takeout tongs set too close
- Takeout tongs cold
- Hand tongs cold or not properly made
- Stacker tongs cold
- Wind blowing on finishes

10. Rough Finishes
    - Dirty plunger and ring
    - Excessive swabbing
    - Too much oil used in delivery
11. Finish Out of Round
    - Not enough counterblow
    - Plunger contact too short
    - Takeout tongs too small or out of shape
    - Neck rings too hot
12. Neck Ring Seams
    - Plunger shoulder diameter too large
    - Ring diameter too small for blank mold
    - Blank mold fit for rings too large
    - Rings not properly matched
    - Blanks standing open due to carbon accumulation
    - Dirty rings and plungers
13. Bent Necks
    - Mold running hot pulling bottle sideways
    - Picking up bottles too early with hand tongs
    - Takeout tongs out of alignment
    - Neck ring running hot
    - Neck rings not relieving properly
14. Chokes in Neck
    - Glass too hot
    - Plunger too long or short
    - Plunger in contact with glass too long
    - Blanks too hot and dry
    - Machine running too slow
    - Drop too pointed
15. Light Shoulders
    - Hot glass
    - Parison too soft (running in blow mold)
    - Blank shape does not suit bottle (shoulders of blank too small)
    - Final blow too late
16. Shoulders Not Blown Up
    - Glass too cold
    - Too much counterblow making too hard a parison
    - Reheat time too short
    - Mold not properly vented
    - Final blow too soon
17. Shoulder Checks
    - Too much final blow pressure
    - Mold not relieving
18. Bottom Plate Seams
    - Pin in plate out of alignment with mold
    - Glass in interlocking fits between mold and plate
    - Warped molds
19. Baffle Marks
    - Parison too hard (too long or too heavy counterblow)
    - Parison reheat too short
    - Baffle out of alignment with blank —not properly matched
    - Bad baffle design
    - Baffle not set properly on blank
20. Heeltaps
    - Uneven temperature of drop (feeder condition)
    - Parison not blown full—too soft
    - Blanks too short
    - Blanks too hot, parison sticking
    - Cooling wind on one side of blank more than other
    - Neck ring arms one higher than the other
    - Neck in mold smaller than blank causing a hang-up
    - Blow mold too hot
    - In general, heeltaps are caused by an improper combination of parison temperature, parison length, and initial final blow time. A proper combination is required, to balance mechanical actions of the forming machine
21. Light Bottom
    - Glass too cold
    - Under weight
    - Incorrect plunger contact time in relation to counterblow (parison blowing through in blank mold)
    - Parison reheat too short
    - Blank shape incorrect
    - Final blow too early
22. Heavy Bottoms
    - Glass too hot
    - Over weight
    - Parison too soft
    - Counterblow not long enough and

too light a counterblowing pressure
Parison reheat too long
Blank too large at bottom
Half bubble parison
Final blow too late

23. Bottom Sunk
    Glass too hot
    Bottom plates too hot (light)
    Cooling wind not sufficient
    Machine running too fast

24. Bottom Plate Checks
    Too much final blowing pressure
    Bottom plate running too hot
    Bottom plate out of alignment with mold
    Mold not relieving

25. Hot Checks
    Molds running too hot
    Too much blowing pressure
    Not enough cooling wind on molds
    Machine running too fast

26. Panel Checks
    Molds running too hot
    Too much blowing pressure
    Molds not properly vented
    Not enough cooling wind
    Machine running too fast

27. Broken Ware
    Cold glass
    Cold molds and blanks
    Too much final blowing pressure
    Too much cooling wind
    Machine running too slow
    Too many bottles standing on buck or conveyor
    Lehr or peanut roaster conditions not uniform

28. Bottles Out of Shape
    Glass too hot
    Blanks too hot
    Molds too hot
    Machine running too fast
    Bottles picked up too soon
    Not enough wind
    Not enough blowing pressure or time

29. Stuck
    Glass too hot
    Machine running too fast
    Bottles taken from conveyor too soon
    Set in lehr too hot
    Temperature of lehr too high

30. Light Sides
    Feeder condition, cold side on drop
    More wind on one half of blank than other

31. Cold Appearance of Bottle
    Glass too cold
    Counterblow too long
    Reheat time too short (crack blank earlier)
    Machine speed too slow
    Blanks running too cold
    Blanks too heavy
    Blow mold too cold
    Not enough final blow

32. Wavy
    Glass too cold
    Uneven temperature of drop (feeder condition)
    Poor delivery
    Settle blow too hard or too long
    Not sufficient reheat time between plunger release and counterblow and between blank crack and final blow
    Blank mold too cold
    Machine running too slow
    Plunger contact time too long

33. Uneven Distribution
    Glass too cold
    Uneven temperature of drop
    Plunger too cold
    Blanks running too cold
    Uneven wind application
    Machine running too slow
    Incorrect blank design
    Fluctuating delivery

34. Large Mold Seams
    Carbon collection or glass between mold halves
    Interlocking bottom plate too large or mold size too small
    Glass in interlocking parts
    Warped molds

35. Large Blank Seams
    Neck ring diameter too large
    Blank fit for rings too small
    Carbon collection between mold halves
    Neck ring arms not set properly
    Warped blanks

36. Shear Marks
    Cold glass
    Shears not cutting centrally
    Too much or not enough shear lap

Loose shears
Worn or defective shear blades
Shears out of alignment, either vertically or laterally
Too much water on shear blades
Carbon or oil accumulation on shear blades
Shear arms out of alignment
Cutting shear cam too slow

37. Brush Marks (Fine Vertical Laps)
Cold glass
Glass chilling in slow delivery (trough delivery)
Glass hanging up in funnels
Blank shape
Plunger in feeder not pulling glass back in orifice, chilling end of gob
Gob too long—diameter too small

38. Oil Marks
Oil accumulation on shears, funnels and troughs

39. Carbon Marks
Caused from feeder burner, too much oil and not enough air (poor mixture)

40. Laps
Drop too long, either too hot or too cold
Shears not cutting centrally
Drop too short hanging up in funnel
Drop too small for blank opening
Blanks too hot and dry

41. Washboards
Drop not entering mold centrally
Uneven temperature of drop
Drop too small and not proper shape for blanks
Funnel too large for body of blank
Carboned or hot funnels
Blanks too hot or too cold
Dirty blank molds
Drop too large in diameter

42. Blisters
Glass level too low
Foreign matter in channel
Tank too hot to allow fire being worked in feeder
Cold glass collects on needle and channel walls
Not enough fire around needle on very cold glass
Needle worked too low in cold glass
Shears cutting too close to needle
Needle rubbing on side of orifice
Orifice ring too large for job
Worn needle point

42-A. Lap Blisters in Neck
Drop too long and small in diameter
Glass not hitting in center of blank
Not enough vent in neck rings or around plunger
Blank running too hot

43. Cords
Cords are a glass condition which usually cannot be detected until they show up in the finished ware. No forming machine adjustment will eliminate cords

44. Iron and Other Streaks
Foreign matter in channel

45. Dirty Blanks and Molds
Note: Never squirt machine oil into molds
Excessive swabbing
Poorly made swabs

Source: Arthur W. Schmid, Pittsburgh, Pa. (*Glass Ind.*, Sept. 1934, page 182.)

SUMMARY OF IMPORTANT DEFECTS IN GLASS AND THEIR

Kinds of Defects	Batch	Melting	Fining	Standing
Stones Knots	Poor granulation Insoluble foreign bodies Lumping, as by freezing	Low temperature Rapid feeding of raw materials Corrosion of refractories Crown droppings	Too rapid current of batch Unequal solution of refractories Dropping of furnace glaze	Formation of devitrification stones, esp. in cooler portion Glaze drops
Cords	Poor mixing Segregation by falling or in transport Unequal granulation Lumping Deficiency of gas formers	Insufficient temp. or time Glass too viscous for heat conditions Flowing apart upon melting Dissolved refractories	Rapid Temperature drop Dissolved refr. Bad floater behavior	Irregular heat distribution Precipitation Local attack on refractories as rings, floaters, etc.
Seeds	Lack of fining agents Unfavorable gas content Unequal granulation	Low temperature Erratic control of temperature Flow separation Gas from refractories Irregular feeding	Low temperature Short time or secondary reactions Viscous glass Furnace atmosphere, trapped at cold surface	Secondary reaction Gas atmosphere Rapid cooling Skin formation trapping bubbles Gas from refractories
Devitrification				Deep layer too cold Too long time at low temperature Poor comp. Foreign matter
Bad Workmanship				
Breakage, Intern. Strain				
Surface Clouding, Decomposition	Excessive alkali	Segregation "Gall" formation	Protracted gall Furnace atmosphere Flying dust and ash	Renewed gall Gall formed by furnace gases Glass too cold Oxidizing gases

Dependence on the Steps of Glass Manufacture

Working	Annealing	Packing-Storage	Use
Thread formation Irregular heat distribution Overlapping Burnt-in oil Action of smoke Solution of refractories			
Bad gathering Trapped air Gassing of coatings Smoke, oil and rust Effects of workings			
Time - temperature ratio wrong for glass High tendency of glass to crystallize	Held too long at upper annealing temperature		
Bad distr. of heat or glass Wrong viscosity Mechanical marking Machine or tool defects	Lehr-melt Wrong adjustment of temperatures Glass too soft		
Too rapid cooling, too "hard" glass Bad adj. of temp. to thickness and size Weakening by grinding Excessive heat during polishing	Wrong adjustment or temperatures Internal strain Temperature shock	Residual strain, scratching Poor packing Shock in shipment	Heat shock, shock, fall Pressure Residual strain Strain from other causes
Inclusion of oil Contact with steam, smoke, dust and dirt	Reaction with combustion gases as SO_2 Dust, fused in	Poor resistance Condensation Damp storage Wet paper Rain	Attack by water or chemicals Resistance too poor for intended purpose

Plate Glass

Grinding, Smoothing, and Polishing Defects

GRINDERS

Scratches:

"Grinder Cuts," caused by large particles in sand.

"Runner cuts," caused by insufficient sand under disk, or hard spot in disk.

Breakage:

"Grinder breakage," sheet badly broken.

"Stars," caused by high spots on sheet or when weight of disk is not entirely down on sheet. These have the appearance of stars as the name implies.

SMOOTHERS

Scratches:

"Garnet clicks," caused by an insufficient amount of garnet. These have a torn appearance and appear black.

Breakage:

Very seldom occurs during smoothing.

POLISHERS

Scratches

"Block runner," wide interrupted scratch, reddish in appearance caused by small cullet chip imbedded in felt. Particles of rust will also cause this.

"Chain," narrow interrupted scratch, reddish in appearance, caused by small cullet chip imbedded in felt.

"Sleeks," a faint hair line scratch in appearance, very shallow, usually 2 in. to 18 in. long, easily removed by hand wheel or block. Caused by insufficient amount of rouge or rouge density too thin.

DEFECTS AFTER FINISH

Grinders:

"Shiners," sand pits caused by insufficient fine sand. Have appearance of minute electric lights under microscope.

Polishers:

"Short finish"—Insufficient polish.

"Felt finish"—Caused by wet felts.

"Burnt finish"—Caused by dry felts on last machines and too much heat, also characteristic of certain rouge.

Devitrification

Phase Equilibrium Studies

The thorough study of soda-lime-silica glasses by Morey and Bowen, portrayed in the triaxial diagrams on succeeding pages, forms the scientific basis for understanding devitrification. This work is done on the basis of the Phase Rule, which for silicate systems may be written (since the vapor phase involving the condition of pressure is disregarded):

$$F = C - P + 1,$$

where F = number of degrees of freedom; C = number of components; P = number of phases.

Definitions:

A *system* is any portion of the universe of matter, isolated for study.

A *phase* (P) is a homogeneous, physically distinct, and mechanically separable portion of the system.

The number of *components* (C) of a system at equilibrium is the smallest number of independently variable constituents necessary to express the composition of each phase.

The degree of *freedom* (F) is the number of the variables, here temperature and concentration, which must be arbitrarily fixed to define the system completely.

Equilibrium in a system such as this is reached when the passage of time brings about no further crystallization or disappearance of crystals.

The *liquidus* of any composition is the temperature at which the liquid and the primary phase are in equilibrium. Above the liquidus, no crystals can form.

The *primary phase* is the first crystalline phase to appear when a liquid of given composition is cooled

at equilibrium, a condition which may require very long standing at constant temperature.

In the triaxial diagram, composition is expressed by the location of a point on the triangle, SiO_2 being plotted toward the lower right, CaO vertically, and Na_2O toward the lower left. The boundary lines in the first diagram mark the *fields*, which are the areas in which the compositions indicated are respective primary phases. The field labelled $Na_2O \cdot 3\ CaO \cdot 6\ SiO_2$ (devitrite), whose own composition lies in the $CaSiO_3$ field, and which melts incongruently, forming a glass and crystals of $CaSiO_3$, is known as the field of commercial glasses because it contains most (but not all) the soda-lime-silica mixtures which are suitable for commercial glasses from the standpoints of fusibility, workability, durability, and freedom from devitrification. If we melt a composition in this field containing: SiO_2, 72 per cent; Na_2O, 16 per cent; and CaO, 12 per cent; and bring it to equilibrium at about 900° C., crystals of the primary phase, devitrite, make their appearance. As a result, the remaining liquid, being poorer in devitrite than the original glass, changes in composition along a line drawn away from the $Na_2O \cdot 3\ CaO \cdot 6\ SiO_2$ point in the upper part of the diagram. Therefore, as cooling proceeds under equilibrium conditions, the composition of this liquid eventually reaches the line PQ. The diagram expresses the fact that a second crystalline phase, tridymite, appears. The remaining liquid now changes in composition toward the point P, where tridymite becomes quartz. With further cooling at equilibrium, quartz and devitrite come out together, and the remaining liquid changes along the line PO. When O is reached, $Na_2O \cdot 2\ SiO_2$ appears as a third crystalline phase. When the phase rule is applied to this situation:

$$F = 3 - 4 + 1 = 0;$$

that is, the point 0 is a ternary eutectic, where there may exist in equilibrium, at fixed temperature and concentration, three crystalline phases and one liquid phase. If the temperature rises ever so little, one crystalline phase disappears; if it falls ever so little, the liquid disappears and complete crystallization occurs.

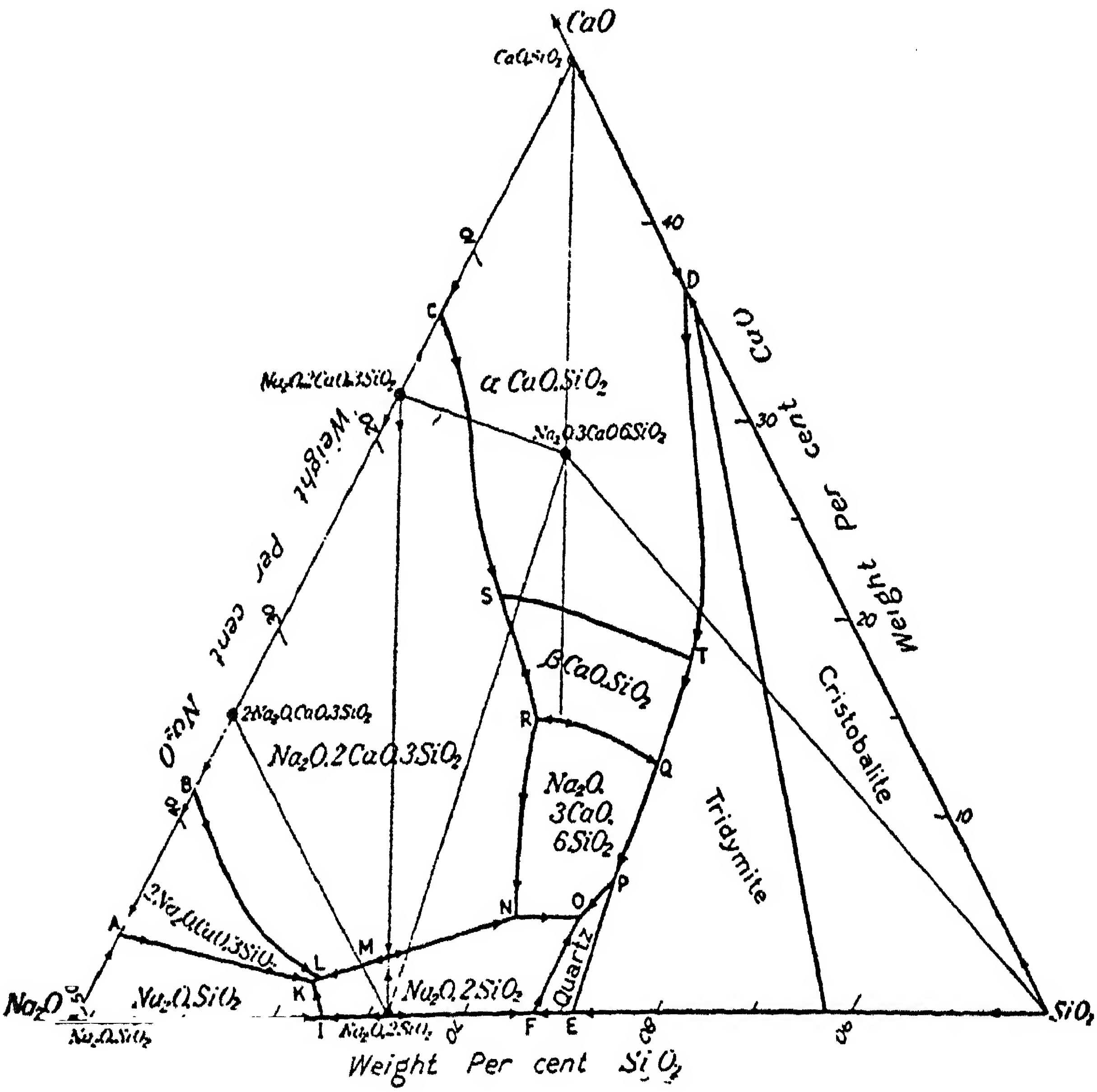
A similar history can be traced for other compositions. If the original glass contains more than 14 per cent CaO with 74 per cent SiO_2, the primary phase is β $CaSiO_3$ (low wollastonite). If the original glass contains about 76 per cent SiO_2, the primary phase is tridymite.

Compositions in the devitrite field are characterized by high viscosity at the liquidus temperature, which means that they are stable as glasses and do not readily devitrify. However, these compositions are not all equally stable. Those higher in lime have higher liquidus temperatures, are less viscous at the liquidus, and devitrify more readily than low-lime compositions.

The second diagram shows *isotherms*, which are lines drawn through composition points having the same liquidus temperature. It will be noted that the point 0 has the lowest liquidus in the system, at 725°C. A solid diagram or model

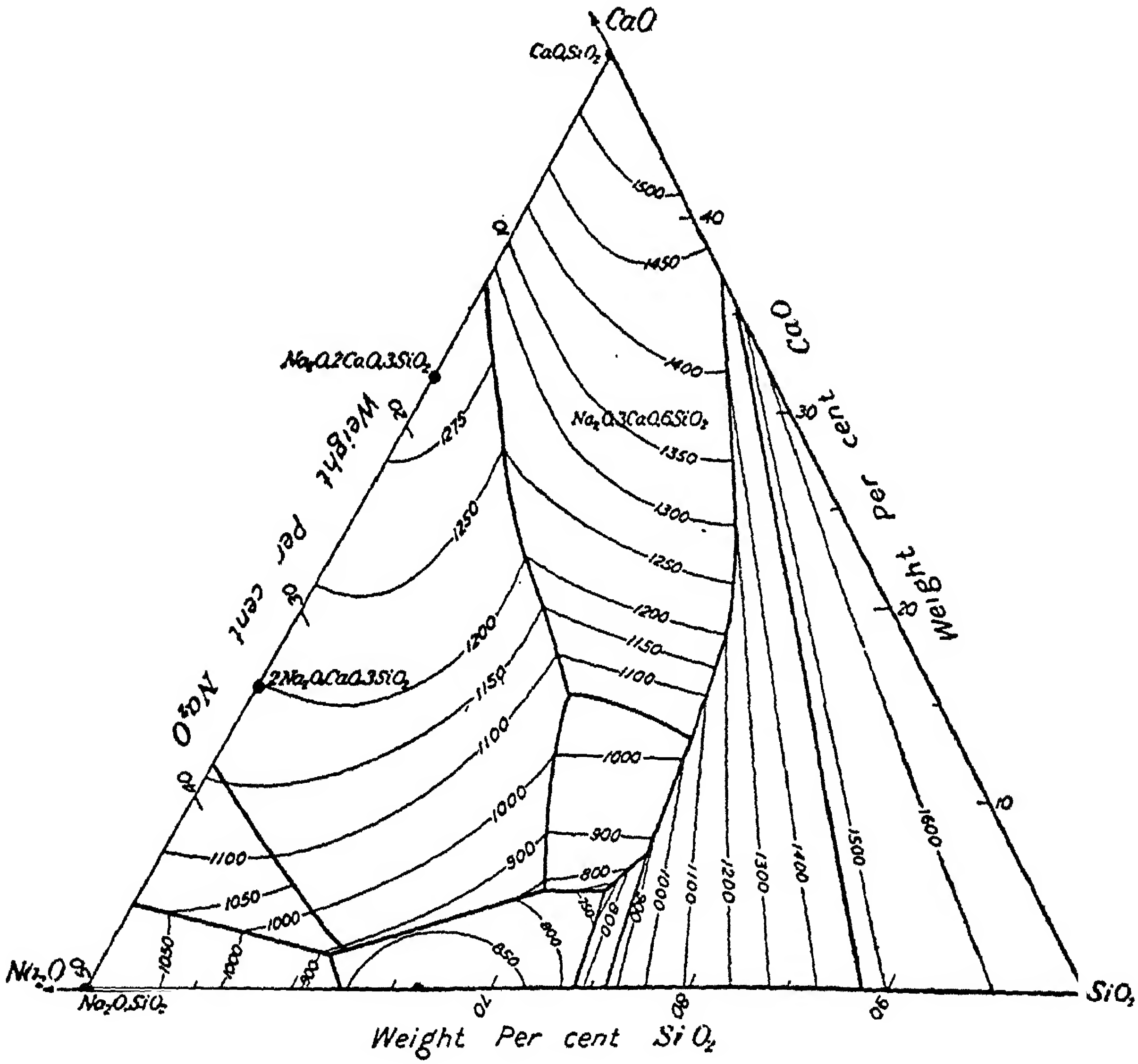
having the triaxial as a base and altitudes corresponding to liquidus temperatures represents a "hilly" region, in which the fields lie on more or less steep slopes, and the boundary lines appear as ravines. The eutectic point is a sink.

Since very few commercial glasses contain only Na_2O, CaO, and SiO_2, this treatment is too simple to describe their behavior, although it indicates in general what may be expected. The addition of other oxides, such as Al_2O_3, B_2O_3, MgO, K_2O,



Phase Equilibrium Diagram of the Ternary System $Na_2O \cdot SiO_2$–$CaO \cdot SiO_2$–SiO_2, Showing Boundary Curves and Tie Lines. (After Morey and Bowen.)

and BaO, modifies the liquidus temperatures and the character of the primary phases. In general, additional oxides lower the liquidus temperatures, and increase viscosities at these temperatures; both of which conditions reduce the tendency toward devitrification. The complication of glass compositions becomes highly important when the working processes involve retention of the glass at low temperatures for extended periods of time, as in drawing sheet glass. It must be remembered that the diagrams described are based on equilibrium conditions reached only after long periods.



PHASE EQUILIBRIUM DIAGRAM OF THE TERNARY SYSTEM $Na_2O \cdot SiO_2$–$CaO \cdot SiO_2$–SiO_2, SHOWING ISOTHERMS. (AFTER MOREY AND BOWEN.)

Optical Characters of Crystals in Glass Stones

Name	Composition	Ng	Nm	Np	Crystal System	Character of Crystals	Other Data
Mullite	$3Al_2O_3 \cdot 2SiO_2$	1.654	1.644	1.642	Orthorhombic	Needles	Z = C; +2V = 45°
Corundum	Al_2O_3	1.768	.....	1.760	Hexagonal	Basal plates	Uniaxial negative
Quartz	SiO_2	1.553	.....	1.544	Hexagonal	No definite shape	Uniaxial negative
Cristobalite	SiO_2	1.487	.....	1.484	Tetragonal (?)	"Pine-tree" skeletons	Uniaxial negative
Tridymite	SiO_2	1.473	1.469	1.469	Orthorhombic	Hex. basal plates, or arrow-shaped twins	+2V = 35°
Devitrite	$Na_2O \cdot 3CaO \cdot 6SiO_2$	1.579	1.570	1.564	Orthorhombic	Needles	Z = C; +2V = 75°
Wollastonite	$CaO \cdot SiO_2$	1.631	1.629	1.616	Monoclinic	Needles	−2V = 39° + or − elongation
Pseudo-wollastonite	$CaO \cdot SiO_2$	1.654	1.610	1.610	Pseudo-hexagonal	Grains	+2E = 0 − 8°
Nephelite	$Na_2O \cdot Al_2O_3 \cdot 2SiO_2$	1.537	.....	1.533	Hexagonal	Grains	Uniaxial negative
Carnegieite	$Na_2O \cdot Al_2O_3 \cdot 2SiO_2$	1.514	1.514	1.509	Triclinic	Lamellar twinning	−2V = 12 − 15°
Diopside	$CaO \cdot MgO \cdot 2SiO_2$	1.69	1.67	1.66	Monoclinic	Grains	+2V = 59 − 60° Z > C = 36 − 40°

Anorthite, Albite, Willemite, Barium silicate, and others are possible, but rare. They arise from local, abnormal compositions in the glass, by devitrification.

References: "Microscopic Characters of Artificial Minerals," by A. M. Winchell. Herbert Insley: "The Microscopic Identification of Stones in Glass," *Jour. Am. Cer. Soc.*, 1924, p. 1418.

Usual Sources of Stones, and Other Comments

Mullite: Fragments of pot or tank-refractory.

Corundum: Pot- or tank-stones that have been in contact with the glass for long periods of time, at high temperatures.

Quartz: Undissolved sand from batch. Frequently surrounded by devitrified halo largely tridymite or cristobalite.

Cristobalite: Grains, from crown drops or spalls from silica brick. Skeletal crystals, principally from devitrification. Stable above 1470 °C. Inversion difficult.

Tridymite: Drop or spalls, scum, devitrification. Stable 870–1470 °C. Inversion difficult.

Devitrite: Devitrification in cooler portions of melt. Usually forms spherulites.

Wollastonite: Devitrification. Stable below 1200 °C.

Pseudo-Wollastonite: Devitrification. Stable below 1200 °C.

Nephelite: Devitrification, or stones from aluminous refractories. Stable below 1248 °C.

Carnegieite: Same, but stable higher than 1248 °C. Diopside: Devitrification.

REFRACTIVE INDICES OF VARIOUS IMMERSION LIQUIDS

Substance	Index, n_D	Temp., °C.	Sp. Gr.	Boiling Point, °C.	Formula	Authority
Air	1.000	...	..	...	....	....
Water	1.334	18.75	1.00	100	H_2O	Fraunhofer
Ethyl Alcohol	1.362	20.0	0.79	78	C_2H_6O	Ketteler
Heptane	1.387	23.0	0.68	98	C_7H_{16}	Gladstone
Chloroform	1.444	20.0	1.49	61	$CHCl_3$	Lorenz
Kerosene	1.448	...	..	...	....	Winchell
Carbon Tetrachloride	1.466	12.3	1.61	77	CCl_4	Gladstone
Glycerine	1.473	20.0	1.26	...	$C_3H_8O_3$	Landolt
Castor Oil	1.478	...	0.96	265+	....	S. R. d. Kolb
Toluol	1.495	20.0	0.87	110	C_7H_8	Brühl
Benzol	1.498	21.5	0.88	80	C_6H_6	Gladstone
Cedar Wood Oil	1.516	...	0.98	237	....	S. R. d. Kolb
Monochlorobenzol	1.527	...	1.13	132	....	S. R. d. Kolb
Canada Balsam	1.54 ±	...	..	...	....	....
Nitro Benzol	1.553	20.0	1.20	209	$C_6H_5NO_2$	Brühl
Orthotoluidine	1.572	...	0.99	198	....	S. R. d. Kolb
Monochloraniline	1.592	...	1.24	207	....	S. R. d. Kolb
Quiniline	1.617	20.0	1.09	237	C_9H_7N	Berliner
Carbon Bisulphide	1.628	20.0	1.26	46	CS_2	Ketteler
Potass.-Merc. Iodide	1.717	18.0	3.11	...	....	Goldschmidt
Methylene Iodide	1.742	19.0	3.32	181	CH_2I_2	Gladstone

Miscible Index Oils

The following oils, recommended by Insley, are miscible in all proportions at ordinary temperatures, are chemically stable, and have approximately the same rate of volatilization. Therefore, index liquids can be made from mixtures of two or more of these four, covering a wide and useful range of indices.

	n_D
Iso-amyl-iso-valerate	1.41
Liquid Petroleum Oil	1.47
Alpha Monobrom Naphthalene	1.66
Methylene Iodide	1.74

Section X

MISCELLANEOUS

Miscellaneous

TWIST DRILLS

Gages, Diameters, and Areas

No.	Diam., In.	Area, In.^{2}
1	0.228	0.04083
2	0.221	0.03836
3	0.213	0.03563
4	0.209	0.03431
5	0.206	0.03333
6	0.204	0.03269
7	0.201	0.03173
8	0.199	0.03110
9	0.196	0.03017
10	0.194	0.02956
11	0.191	0.02865
12	0.189	0.02806
13	0.185	0.02688
14	0.182	0.02602
15	0.180	0.02545
16	0.177	0.02461
17	0.173	0.02351
18	0.169	0.02243
19	0.166	0.02164
20	0.161	0.02036
21	0.159	0.01986
22	0.157	0.01936
23	0.154	0.01863
24	0.152	0.01815
25	0.150	0.01767
26	0.147	0.01697
27	0.144	0.01629
28	0.140	0.01539
29	0.136	0.01453
30	0.128	0.01287
31	0.120	0.01131
32	0.116	0.01057
33	0.113	0.01003
34	0.111	0.00968
35	0.110	0.00950
36	0.107	0.00899
37	0.104	0.00849
38	0.102	0.00817
39	0.100	0.00785
40	0.098	0.00754
41	0.096	0.00724
42	0.093	0.00679
43	0.089	0.00622
44	0.086	0.00581
45	0.082	0.00528
46	0.081	0.00515
47	0.078	0.00478
48	0.076	0.00454
49	0.073	0.00419
50	0.070	0.00385
55	0.052	0.00212
60	0.040	0.00125
65	0.035	0.00096
70	0.028	0.00062
75	0.021	0.00035
80	0.013	0.00013

TWIST DRILLS

Letter	Diam., In.	Area, In.^{2}
A	0.234	0.04301
B	0.238	0.04449
C	0.242	0.04510
D	0.246	0.04753
E	0.250	0.04909
F	0.257	0.05187
G	0.261	0.05350
H	0.266	0.05557
I	0.272	0.05811
J	0.277	0.06026
K	0.281	0.06202
L	0.290	0.06605
M	0.295	0.06835
N	0.302	0.07163
O	0.316	0.07843
P	0.323	0.08194
Q	0.332	0.08657
R	0.339	0.09026
S	0.348	0.09511
T	0.358	0.10066
U	0.368	0.10636
V	0.377	0.11163
W	0.386	0.11702
X	0.397	0.12379
Y	0.404	0.12819
Z	0.413	0.13396

CONTENTS OF HORIZONTAL CYLINDRICAL TANKS WHEN FILLED TO VARIOUS DEPTHS

Tanks with Flat Ends—Contents in U. S. Gallons per 1 Foot of Length

Diam. of Tank, In.	Full Tank	Depth of liquid in inches = h. 3	6	9	12	15	18	21	24	27	30	33	36	39	42	45	48	51	54
12	5.88	1.15	2.94																
18	13.22	1.45	3.86	6.61															
24	23.50	1.70	4.60	8.05	11.75														
30	36.72	1.91	5.23	9.27	13.72	18.36													
36	52.88	2.12	5.79	10.34	15.43	20.85	26.44												
42	71.97	2.28	6.31	11.31	16.97	23.07	29.47	35.99											
48	94.01	2.45	6.78	12.00	18.38	25.10	32.20	39.54	47.00										
54	118.98	2.60	7.22	13.04	19.68	26.97	34.72	42.80	51.08	59.49									
60	146.89	2.75	7.64	13.82	20.91	28.72	37.06	45.82	54.87	64.11	73.44								
66	177.73	2.89	8.04	14.56	22.07	30.37	39.28	48.65	58.39	68.41	78.59	88.86							
72	211.52	3.02	8.42	15.26	23.17	31.92	41.36	51.32	61.71	72.45	83.41	94.54	105.76						
78	248.24	3.15	8.78	15.94	24.21	33.41	43.34	53.86	64.87	76.27	87.97	99.90	111.97	124.13					
84	287.90	3.26	9.12	16.57	25.24	34.85	45.24	56.29	67.87	79.91	92.30	104.98	117.85	130.87	143.95				
90	330.49	3.43	9.46	17.20	26.20	36.21	47.05	58.61	70.75	83.39	96.43	109.81	123.45	137.28	151.23	165.25			
96	376.02	3.50	9.79	17.80	27.13	37.52	48.81	60.84	73.52	86.73	100.39	114.44	128.79	143.40	158.17	173.06	188.01		
102	424.50	3.61	10.10	18.37	28.01	39.00	50.49	62.99	76.18	89.94	104.20	118.89	133.92	149.25	164.81	180.53	196.37	212.25	
108	476.10	3.71	10.39	18.94	28.90	40.03	52.14	65.09	78.74	93.04	107.87	123.17	138.87	154.89	171.19	187.71	204.37	221.14	238.05
114	530.25	3.78	10.74	19.49	29.75	41.22	53.73	67.10	81.24	96.05	111.43	127.31	143.63	160.33	177.33	194.60	212.05	229.65	247.37
120	587.54	3.91	10.98	20.02	30.57	42.39	55.26	69.06	83.65	98.95	114.87	131.32	148.25	165.58	183.27	201.24	219.46	237.87	256.43

To ascertain contents of tank, multiply number of gallons from above table by length of tank in feet.

To ascertain contents of tank over one-half full, measure height of empty portion of tank. In the above table, find the quantity corresponding to this height and subtract this quantity from the contents of a full tank. Multiply this by the length of the tank.

Source. Ceramic Data Book.

TYLER STANDARD SCREEN SCALE

Mesh	Tyler Standard Screen Scale $\sqrt{2}$ or 1.414 Openings, In.	For Closer Sizing Sieves from 0.0015 In. to 3.000 In. Ratio $\sqrt[4]{2}$ or 1.189	Opening, Mm.	Diam. of Wire, Inch	U. S. Series Equiv. No.
...	....	3	....	0.207	...
...	....	2	....	0.192	...
...	....	1.5	....	0.148	...
...	1.050	1.050	26.67	0.148	...
...	....	0.883	22.43	0.135	...
...	....	0.742	18.85	0.135	...
...	....	0.624	15.85	0.120	...
...	0.525	0.525	13.33	0.105	...
...	....	0.441	11.20	0.105	...
...	0.371	0.371	9.423	0.092	...
2 1/2	....	0.312	7.925	0.088	...
3	0.263	0.263	5.680	0.070	...
3 1/2	....	0.221	5.613	0.065	...
4	0.185	0.185	4.699	0.065	4
5	....	0.156	3.962	0.044	5
6	0.131	0.131	3.327	0.036	6
7	....	0.110	2.794	0.0328	7
8	0.093	0.093	2.362	0.032	8
9	....	0.078	1.981	0.033	10
10	0.065	0.065	1.651	0.035	12
12	....	0.055	1.397	0.028	14
14	0.046	0.046	1.168	0.025	16
16	....	0.0390	0.991	0.0235	18
20	0.0328	0.0328	0.833	0.0172	20
24	....	0.0276	0.701	0.0141	25
28	0.0232	0.0232	0.589	0.0125	30
32	....	0.0195	0.495	0.0118	35
35	0.0164	0.0164	0.417	0.0122	40
42	....	0.0138	0.351	0.0100	45
48	0.0116	0.0116	0.295	0.0092	50
60	....	0.0097	0.246	0.0070	60
65	0.0082	0.0082	0.208	0.0072	70
80	....	0.0069	0.175	0.0056	80
100	0.0058	0.0058	0.147	0.0042	100
115	....	0.0049	0.124	0.0038	120
150	0.0041	0.0041	0.104	0.0026	140
170	....	0.0035	0.089	0.0024	170
200	0.0029	0.0029	0.074	0.0021	200
250	....	0.0024	0.061	0.0016	230
270	0.0021	0.0021	0.053	0.0016	270
325	....	0.0017	0.043	0.0014	325
400	0.0015	0.0015	0.038	0.001	...

(Courtesy, The W. S. Tyler Co.)

U. S. Standard Screens

Sieve No.	Sieve Opening, In.	Sieve Opening, Mm.	Diameter Wire, In.
4	0.187	4.76	0.050
8	0.0937	2.38	0.0331
10	0.0787	2.00	0.0299
16	0.0469	1.19	0.0213
20	0.0331	0.84	0.0165
30	0.0232	0.59	0.0130
40	0.0165	0.42	0.0098
50	0.0117	0.297	0.0074
60	0.0098	0.250	0.0064
70	0.0083	0.210	0.0055
80	0.0070	0.177	0.0047
100	0.0059	0.149	0.0040
200	0.0029	0.074	0.0021
325	0.0017	0.044	0.0014

Electric Heating

Volts × Amperes = Watts.
Watts × 3.41 = B.t.u./hr.
1 Amp. at 110 V. = 375 B.t.u./hr.
Amp. = V. ÷ R (ohms).
Watt = V. × Amp. = $V.^2 \div R$.

For constant voltage, the power consumed and the heat generated in a resistance wire of given diameter vary inversely as its length.

Data on Chromel "A" Wire

B. & S. Gage	Ohms per Ft.	Ft. for 500 W. at 110 V.	W. for 30 Ft. at 110 V.
18	0.406	60	1000
20	0.635	38	634
22	1.017	24	400
24	1.61	15	250
26	2.57	9.5	158
28	4.10	6.2	103
30	6.50	3.7	62

Wave Lengths of Various Radiations

	Ångstroms
Cosmic Rays	0.0005
Gamma Rays	0.010–1.40
X-Rays	10–150
Ultra-Violet, below	4000
Limit of Sun's U.-V. at earth's surface	2920
Visible Spectrum	4000–8000 (?)
Violet, representative 4100, limits	4000–4240
Blue, representative 4700, limits	4240–4912
F-line (Hydrogen)	4861
Green, representative 5200, limits	4912–5750
Maximum Visibility, about	5560
Yellow, representative 5800, limits	5750–5850
D-line (Sodium)	5893
Orange, representative 6000, limits	5850–6470
Red, representative 6500, limits	6470–8000 (?)
C-line (Hydrogen)	6563
Infra-Red, greater than	8000
Hertzian Waves, greater than	2.2×10^6
Used for radio or wireless	100–5000 meters

1 Ångstrom unit (Å.) = 0.1 mμ = 0.0001μ = 10^{-7} mm. = 10^{-8} cm.
1 micron (μ) = 1000 mμ = 10,000 Å. = 10^{-3} mm. = 10^{-4} cm. = 10^{-6} m.
1 millimicron (mμ) = 0.001μ = 10 Å. = 10^{-6} mm. = 10^{-7} cm.

Source: C. R. Handbook.

Note: The color of a glass is scientifically represented by its transmission *vs.* wave-length curve.

Laboratory Recipes

Acid Proof Wood Stain

Solution No. 1

Copper Sulfate	125 g.
Potassium Chlorate	125 g.
Water	1000 cc.

Solution No. 2

Aniline	150 g.
Conc. Hydrochloric Acid	180 g.
Water	1000 cc.

To the clean, bare wood, apply two coats of boiling hot solution No. 1, with a brush, allowing each coat to dry before the next is applied. Then apply two coats of solution No. 2, similarly. When the job is completely dry, wash off excess chemicals with hot soapsuds, then finish with raw linseed oil and rub to a polish. Re-polish with linseed oil when necessary.

Cements for Use with Glass

(1) Sodium silicate (water glass) thickened with finely powdered barium sulfate and sodium fluosilicate may be used to cement glass to glass.

(2) Shellac two parts, Venice turpentine one part, fused together and cast in sticks and melted for use as required.

(3) A cement made from gelatin, dissolved in $1^1/_2$ times its weight of strong acetic acid to which 5% ammonium dichromate has been added, forms a glue or cement which will become insoluble after exposure to direct sunlight.

Etching Solutions

Deep etching, as for needle or plate etching, is done with clear hydrofluoric acid, full strength (60%) or less. The roughness or "color" of the lines or surfaces is increased by potash or lime in the glass and is decreased by soda or lead. Satin finish, or matt, etching is done with "white acid" which is ammonium bifluoride to which hydrofluoric acid may be added. This is conveniently applied as a paste made by the addition of powdered barium sulfate to the desired consistency. This paste is applied with a brush. Polishing acid consists of a mixture of hydrofluoric and sulfuric acids. Little or no sulfuric acid is necessary for high-lead glasses; about a one-to-one mixture is necessary for lime glasses; and an intermediate mixture for light lead or mixed glasses. The sulfuric acid is added very slowly to the hydrofluoric acid, *never the reverse*. Some polishers prefer to use the mixture hot, in lead pans.

Silvering Glass

Solution No. 1

Silver nitrate	5 g.
Water	300 cc.

Strong Ammonia to dissolve most of the precipitate, filter and make up to 500 cc.

Solution No. 2

Silver Nitrate	1 g.
Water	500 cc.
Rochelle Salt	0.83 g.

Boil until the precipitate collects, filter and add water to make 500 cc.

For silvering, use equal volumes of the two solutions. The glass must be cleaned very thoroughly. About one hour is required for a heavy deposit, but a half-silvered film, suitable for use with the interferometer, may be obtained in about one minute.

Condensed from C. R. Handbook and Sci. Amer. Handybook.

GRINDING SAND
Screen Analyses

Sand	No. of Screen	10	20	30	40	50	80	100	200	<200
	Min. Particles, Mm. Diam.	2.00	0.84	0.59	0.42	0.279	0.177	0.149	0.074	...
No. 1 rough	% retained	0.2	2.6	2.2	7.0	12.8	30.0	7.2	20.1	17.2
No. 2 rough	% retained	...	0.1	0.1	0.6	5.0	2.2	40.0	35.5	16.1
No. 3	% retained	...	...	...	...	...	0.1	Trace	19.6	78.4
No. 4	% retained	...	...	...	...	...	...	Trace	3.0	96.1
No. 5	% retained	...	...	...	...	...	...	...	Trace	99.6
No. 6	% retained	...	...	...	...	...	...	...	Trace	99.4

Grain Diam. by Microscope, Mm.

	Max.	Aver.	Min.
No. 5	0.06	0.05	0.02 to 0.03
No. 6	0.05	0.03 to 0.04	0.01 to 0.02

Rouge (Fe_2O_3), Density of Suspension for Polishing Glass

(Mixed with water)

Beginning of operation—1.02 sp. gr.—2.85°Bé.

End of operation—1.015 sp. gr.—2.15°Bé.

Copperas (Ferrous Sulfate, $FeSO_4.7H_2O$) is usually added at the rate of 5 lb. to 10 lb. per 100 gallons of water, according to operating requirements.

Before mixing the rouge with water, it is sifted through silk cloth. Physical characteristics are hardness, shape, and sharpness of edges, as seen under the microscope.

Garnet Density

When garnet is used for smoothing the glass after grinding and before polishing, the garnet must al pass through a 200-mesh screen after being ground in a ball mill. The density should be from 10°Bé. to 16°Bé., and usually about 8 grades are used. The different grades are obtained by levigating means.

The above are average values, and may differ from individual plant standards, depending upon methods and speeds.

Many present manufacturers are using fine sand instead of garnet or emery with a very material saving in cost. When this is done, it is necessary to provide more find sand tanks and the water temperature must be thermostatically controlled because the rate of settling is controlled by the viscosity of the water.

Glass Container Tolerances

A. Applying to Glass Finish Specifications

Through its Standardization Committee, the Glass Container Association has issued blueprints setting forth standard specifications covering all of the different types of glass finishes.

These specifications apply to the finished glass, rather than to the neck rings and they set forth the permissible tolerances applying to the dimensions and radii. Due to the fact that a number of the present finishes were in use prior to the standardization program, the tolerances shown are not in all instances uniform or consistent as between similar sizes of different finishes.

As a guide and with the thought of gradually achieving greater uniformity, the Standardization Committee has recommended a uniform schedule of Minimum tolerances. This schedule will be applied in

Minimum Tolerances for Standard Glass Finishes

No. or Size	Outside or Overall Diameters. (See Note 1)	Vertical Dimensions to Underside of Lug or Crimp Ring. (See Note 2)	"S" or Similar Dimensions. (See Note 3)	"H" or Similar Dimensions. (See Note 4)
8 to 12, inc.	0.010″	0.010″	0.010″	0.015″
13 to 17, inc.	0.015	0.010	0.010	0.015
18 to 25, inc.	0.020	0.010	0.015	0.020
26 to 34, inc.	0.025	0.015	0.015	0.025
35 to 44, inc.	0.030	0.015	0.020	0.030
45 to 54, inc.	0.035	0.015	0.020	0.030
55 to 80, inc.	0.040	0.015	0.025	0.035
81 to 120, inc.	0.050	0.015	0.030	0.040
121 to 155, inc.	0.060	0.020	0.035	0.045

NOTES

1. Outside or overall diameters which are essential for correct fit of closure should be specified in decimals, with maximum and minimum, and should conform to tolerance chart.
2. Vertical dimensions to underside of lugs or crimp rings which are essential to the correct fit of closure should be specified in decimals, with maximum and minimum, and should conform to tolerance chart.
3. "S" or similar dimensions (the distance from the top of a finish down to the start of a thread or lug) which are essential to the correct fit of closure should be specified in decimals, with maximum and minimum, and should conform to tolerance chart.
4. "H" or similar dimensions (the distance from the top of a finish down to a bead or shoulder below the bottom of the closure) where cap fit is not involved, except for clearance, should be specified in decimals, with maximum and minimum, and should conform to tolerance chart.
5. All other dimensions which are not essential to the proper fit of closure should be specified in common fractions, with a tolerance of plus or minus $^1/_{64}$ in.
6. All radii should be specified in even fractions of $^1/_{64}$ in., or multiples thereof, or in decimal equivalents.
7. No radius of less than 0.016″ should be used.

establishing specifications for new finishes and, where practical, will be applied to revisions of existing finishes. The application of this schedule is recommended to the individual glass container manufacturer in connection with any finish development work.

B. Applying to Capacity, Weight, and Body Specifications

Through its Design and Specifications Committee, the Glass Container Association has issued blueprints setting forth standard specifications covering various lines of containers commonly regarded as stock lines. Permissible tolerances are provided for capacity, weight, and the various body specifications.

The following schedule of tolerances is recommended for food containers, liquor and wine bottles, pharmaceutical and proprietary, and general purpose ware.

This schedule is also recom-

Capacity, Weight, and Body Tolerances of Glass Containers, Not Including Milks, Pressure Bottles or Pressed Ware

(*A*) Capacity of Container to, but Not Including	(*C*) Capacity Tolerance Either Way	(*W*) Weight Tolerance Either Way	(*B*) Body Tolerances, Width, Thickness, Diameter and Height Either Way
$^1/_8$ oz. to $^1/_2$ oz.	$^1/_{64}$ oz.	$^1/_{16}$ oz.	$^1/_{32}$
$^1/_2$ to 2	$^1/_{32}$	$^1/_8$	$^1/_{32}$
2 to 3	$^1/_{16}$	$^3/_{16}$	$^1/_{32}$
3 to 6	$^3/_{32}$	$^1/_4$	$^1/_{32}$
6 to 8	$^1/_8$	$^5/_{16}$	$^1/_{16}$
8 to 10	$^3/_{16}$	$^3/_8$	$^1/_{16}$
10 to 16	$^1/_4$	$^1/_2$	$^1/_{16}$
16 to 24	$^5/_{16}$	$^5/_8$	$^1/_{16}$
24 to 34	$^3/_8$	$^5/_8$	$^1/_{16}$
34 to 70	$^1/_2$	$1^1/_4$	$^1/_{16}$
70 to 96	$^3/_4$	2	$^1/_{16}$
96 to 130	1	$2^1/_2$	$^3/_{32}$
130 to 160	$1^1/_2$	$3^3/_4$	$^3/_{32}$
160 to $1^1/_2$ gal.	2	5	$^3/_{32}$
$1^1/_2$ gal. to 2	3	$7^1/_2$	$^3/_{32}$
2 to 3	4	10	$^1/_8$
3 to 5	6	15	$^1/_8$
5 and over	8	20	$^1/_8$

NOTES

1. The capacity (*C*) and weight (*W*) tolerances are based on commercial practice.
2. The body (B) tolerances do not apply to mold measurements, but are for uncontrollable variations in glass.
3. The weight (*W*) tolerances are not equivalent to the allowable tolerances in capacity (*C*) but are consistent with commercial practice.
4. Adjust weight (*W*) to retain capacities (*C*) within the specified tolerances.

mended to the individual manufacturer in connection with the setting up of glass container drawings either for his own use or for the use of customers.

It is pointed out that the ideal goal in connection with all of these schedules is that glass should be produced to Mean dimensions, that is, half-way between the Maximum and Minimum dimensions.

Tachometers

A tachometer indicates or records the speed of a process. It essentially consists of a generator which develops an electromotive force proportional to its speed and a measuring instrument which indicates or records this E.M.F.

Pressure Gages

A pressure gage is a device which responds to pressure changes. The Bourdon type is used for relatively high pressures and balanced, oil-immersed bells are used for low pressures. Gages can be obtained to measure pressures ranging from the very low ones found in glass-melting furnaces to the high pressures of compressed air in automatic machines and compressors.

Flow Meters

The principle of a flow meter is the measurement of pressure drop across a restriction in a line carrying the stream of gas. These, like the instruments mentioned in the preceding paragraphs, may be adapted to control operations.

POWER REQUIREMENTS

Machine	Capacity	H. P.
Mixers, All Types	90 lb./cu. ft.—12–15 batches/hr.	8 h. p. ton
Mixers, Horizontal Drum (*a*)	1000 lb.—5 t./hr.	5
Mixers, Horizontal Drum (*a*)	2000 lb.—12 t./hr.	10
Mixers, Horizontal Drum (*b*)	1800 lb.—11 t./hr.	7.5
Mixers, Vertical Drum (*c*)	800–1800 lb.—6–13 t./hr.	15
Elevator: Buckets 5″ × 8″	5–12 t./hr.	3–5
Elevator: Buckets 6″ × 10″	15 t./hr.	5–7.5
Elevator: Buckets 7″ × 14″	18 t./hr.	5–10
Cullet Crusher Jaw 6″ × 12″	3–6 t./hr.	6–7.5
Cullet Crusher Jaw 8″ × 15″	6–10 t./hr.	7.5–10

Source: Equipment manufacturers.

Bottle Weights

(Formula: Oz. per piece × 9 = lb. per gross)

Oz. per Bottle	Lb. per Gross	Oz. per Bottle	Lb. per Gross	Oz. per Bottle	Lb. per Gross	Oz. per Bottle	Lb. per Gross
$^1/_2$	$4^1/_2$	$11^1/_2$	$103^1/_2$	$22^1/_2$	$202^1/_2$	37	333
$^3/_4$	$6^3/_4$	$11^3/_4$	$105^3/_4$	$22^3/_4$	$204^3/_4$	$37^1/_2$	$337^1/_2$
1	9	12	108	23	207	38	342
$1^1/_4$	$11^1/_4$	$12^1/_4$	$110^1/_4$	$23^1/_4$	$209^1/_4$	$38^1/_2$	$346^1/_2$
$1^1/_2$	$13^1/_2$	$12^1/_2$	$112^1/_2$	$23^1/_2$	$211^1/_2$	39	351
$1^3/_4$	$15^3/_4$	$12^3/_4$	$114^3/_4$	$23^3/_4$	$213^3/_4$	$39^1/_2$	$355^1/_2$
2	18	13	117	24	216	40	360
$2^1/_4$	$20^1/_4$	$13^1/_4$	$119^1/_4$	$24^1/_4$	$218^1/_4$	$40^1/_2$	$364^1/_2$
$2^1/_2$	$22^1/_2$	$13^1/_2$	$121^1/_2$	$24^1/_2$	$220^1/_2$	41	369
$2^3/_4$	$24^3/_4$	$13^3/_4$	$123^3/_4$	$24^3/_4$	$222^3/_4$	$41^1/_2$	$373^1/_2$
3	27	14	126	25	225	42	378
$3^1/_4$	$29^1/_4$	$14^1/_4$	$128^1/_4$	$25^1/_4$	$227^1/_4$	$42^1/_2$	$382^1/_2$
$3^1/_2$	$31^1/_2$	$14^1/_2$	$130^1/_2$	$25^1/_2$	$229^1/_2$	43	387
$3^3/_4$	$33^3/_4$	$14^3/_4$	$132^3/_4$	$25^3/_4$	$231^3/_4$	$43^1/_2$	$391^1/_2$
4	36	15	135	26	234	44	396
$4^1/_4$	$38^1/_4$	$15^1/_4$	$137^1/_4$	$26^1/_4$	$236^1/_4$	$44^1/_2$	$400^1/_2$
$4^1/_2$	$40^1/_2$	$15^1/_2$	$139^1/_2$	$26^1/_2$	$238^1/_2$	45	405
$4^3/_4$	$42^3/_4$	$15^3/_4$	$141^3/_4$	$26^3/_4$	$240^3/_4$	$45^1/_2$	$409^1/_2$
5	45	16	144	27	243	46	414
$5^1/_4$	$47^1/_4$	$16^1/_4$	$146^1/_4$	$27^1/_4$	$245^1/_4$	$46^1/_2$	$418^1/_2$
$5^1/_2$	$49^1/_2$	$16^1/_2$	$148^1/_2$	$27^1/_2$	$247^1/_2$	47	423
$5^3/_4$	$51^3/_4$	$16^3/_4$	$150^3/_4$	$27^3/_4$	$249^3/_4$	$47^1/_2$	$427^1/_2$
6	54	17	153	28	252	48	432
$6^1/_4$	$56^1/_4$	$17^1/_4$	$155^1/_4$	$28^1/_4$	$254^1/_4$	$48^1/_2$	$436^1/_2$
$6^1/_2$	$58^1/_2$	$17^1/_2$	$157^1/_2$	$28^1/_2$	$256^1/_2$	49	441
$6^3/_4$	$60^3/_4$	$17^3/_4$	$159^3/_4$	$28^3/_4$	$258^3/_4$	$49^1/_2$	$445^1/_2$
7	63	18	162	29	261	50	450
$7^1/_4$	$65^1/_4$	$18^1/_4$	$164^1/_4$	$29^1/_4$	$263^1/_4$	$50^1/_2$	$454^1/_2$
$7^1/_2$	$67^1/_2$	$18^1/_2$	$166^1/_2$	$29^1/_2$	$265^1/_2$	51	459
$7^3/_4$	$69^3/_4$	$18^3/_4$	$168^3/_4$	$29^3/_4$	$267^3/_4$	$51^1/_2$	$463^1/_2$
8	72	19	171	30	270	52	468
$8^1/_4$	$74^1/_4$	$19^1/_4$	$173^1/_4$	$30^1/_2$	$274^1/_2$	$52^1/_2$	$472^1/_2$
$8^1/_2$	$76^1/_2$	$19^1/_2$	$175^1/_2$	31	279	53	477
$8^3/_4$	$78^3/_4$	$19^3/_4$	$177^3/_4$	$31^1/_2$	$283^1/_2$	$53^1/_2$	$481^1/_2$
9	81	20	180	32	288	54	486
$9^1/_4$	$83^1/_4$	$20^1/_4$	$182^1/_4$	$32^1/_2$	$292^1/_2$	$54^1/_2$	$490^1/_2$
$9^1/_2$	$85^1/_2$	$20^1/_2$	$184^1/_2$	33	297	55	495
$9^3/_4$	$87^3/_4$	$20^3/_4$	$186^3/_4$	$33^1/_2$	$301^1/_2$	$55^1/_2$	$499^1/_2$
10	90	21	189	34	306	56	504
$10^1/_4$	$92^1/_4$	$21^1/_4$	$191^1/_4$	$34^1/_2$	$310^1/_2$	$56^1/_2$	$508^1/_2$
$10^1/_2$	$94^1/_2$	$21^1/_2$	$193^1/_2$	35	315	57	513
$10^3/_4$	$96^3/_4$	$21^3/_4$	$195^3/_4$	$35^1/_2$	$319^1/_2$	$57^1/_2$	$517^1/_2$
11	99	22	198	36	324	58	522
$11^1/_4$	$101^1/_4$	$22^1/_4$	$200^1/_4$	$36^1/_2$	$328^1/_2$	60	540

Trademarks of Glass Container Companies

ANCHOR HOCKING		KNOX LETTERS OF PLANTS APPEAR IN KEYSTONE SEE BELOW·	K
ARMSTRONG CORK CO.	A	LAMB	L
BALL BROS CO.	Ball	LATCHFORD-MARBLE	L
BROCKWAY	Brockway B	LAURENS	LGW
BUCK GLASS CO.	B	LIBERTY	LG
CARR-LOWREY		MARYLAND GLASS CORP.	M
CHATTANOOGA	C	MAYWOOD	MG
DIAMOND		NORTHWESTERN	NW
DOMINION	D	OBEAR-NESTER	N
FAIRMOUNT	F F	OWENS-ILLINIOS	Duraglas I
FLORIDA GLASS CO.	FG	OLEAN	
FOSTER-FORBES		PIERCE	P
GAYNER	G G	F.E REED	R
GLASS CONTAINERS INC.		STERLING	S
GLENSHAW	G	SWINDELL	S
J T. & A. HAMILTON	H	THATCHER	
HAZEL-ATLAS		TYGART VALLEY	
KERR	Kerr	UNIVERSAL	UGP
KIMBLE	K	T.C. WHEATON	T.C.W.-CO.

J - JACKSON
K - KNOX
K - MARIENVILLE
M - METRO
K - OIL CITY
P - PENN BOTTLE
P - WIGHTMAN

Glossary of Glass-House Terms

Term	*Derivation*	*Definition*
Alabaster	Resemblance to mineral	A milky white glass diffusing light completely without fire
Alkali	Fr. "alcali" from Arabic "alquali," ashes of saltwort	In glass, the oxide of sodium, potassium, or lithium
Anneal	A. S. "on" plus "aelant," to burn on	To remove strain by controlled heating and cooling
Bait	Fishing	The iron bar dipped into molten glass to start sheet drawing
Bead	Middle English "bede;" prayer, bead	The rounded edge of a tumbler or other piece of ware
Blister	Resemblance	Large bubble, often superficial
Blocking	Wooden block used	(1) Shaping a gather in a cavity in wood or metal (2) Stirring glass by immersion of a wooden block or other source of bubbles
Breast wall	Obvious	Front wall of working end of tank, usually semicircular
Bridgewall	Resemblance	Single or double wall separating two tank compartments
Butterfly valve	Similarity to butterflies' wings in shape and movement	A hinged or pivoted flat damper
Check	In mining, a slight fault	A tiny crack, usually caused by contact of hot glass with a cold surface
Checkers	The game	Open brickwork for heat storage and transfer
Cord	Obvious	Inhomogeneities in glass, having a stringy or fibrous appearance

Crown	Resemblance of central portion of disk to a crown	(1) Originally flat glass made by spinning a blown globe to a flat disk (2) An optical glass having low index of refraction and low dispersion (ν greater than 55)
Crown	Obvious	Arched roof or cap of a furnace
Crystal	Gr. "krystallos" < "kryos," frost; having the clarity of crystal	(1) Colorless glass (2) More specifically, a potash-lead glass for fine tableware
Cullet	Fr. "collet," collar	Waste or cut-off glass
Debiteuse	French	A slotted, floating clay block through which glass issues in the Fourcault process
Devitrification	L. "de.," away from; vitrum, glass	Crystallization in glass partially changing vitreous state
Doghouse	Resemblance	Charging vestibule
Dummy	Counterfeit of human being	A device for wetting, opening and closing blowmolds
English crystal	Source	A glass for cutting having the approximate composition $K_2O \cdot PbO \cdot 6SiO_2$
Finish	Final operation	In particular the top of a bottle as prepared for cork, cap or seal
Flashing	Originally reheating; because of sudden change in appearance	Covering crystal glass with a thin layer of colored or translucent glass
Flint	Variety of cryptocrystalline quartz occurring as pebbles, former source of silica for fine glassmaking	(1) Pulverized quartz (silica) (2) A colorless glass (3) Optical glass; a lead-bearing optical glass of high dispersion (ν less than 50)
Flux	La. "fluxus," flowed	A substance that helps melt
Gaffer	Eng. "foreman"	The head workman on a hand shop
Glass gall	Bitter taste	Layer of molten sulphates floating upon glass

Glory hole	Opening in furnace wall exposing radiation and flames	An opening exposing hot interior of a furnace. Used for reheating ware in handworking
Gob	Abbr. of gobbet, Fr. "gobet"	A portion of hot glass delivered by a feeder
Grog	Fr. "grograin," coarse grain	Ground burnt clay added to a fire clay body
Jamb	Old Fr. "jambe," leg	Side-wall of superstructure carrying port openings
Lehr (Leer)	Ger. "leer Ofen," empty furnace	A chamber in which glass can be cooled gradually to avoid or control stresses in the glass
Marver	Fr. "marbre"	A flat plate on which a gather of glass is rolled
Mold	Fr. "moule" < La. "modulus" from "modus," measure	Form for shaping glass
Moonstone	Resemblance	A type of opal glass
Mould	Same as "mold"	British spelling
Muffle	Du. "moffel," a mitten	A furnace chamber enclosed against the surrounding fire
Murgatroyd belt	An English technologist	A vulnerable zone including the bottom of a bottle and one inch above it
Mushroom valve	Resemblance	A circular adjustable stopper for a gas orifice
Neck	Anatomy	Connection between two parts of a furnace
Nose	Its shape and position	The working chamber of the tank
Opal	Resemblance to gem	A translucent glass transmitting fiery light
Optic	From the illusive appearance created	Lines or marks impressed on a parison before final blowing; also vertical lines in pressed ware formed by special plunger
Parison	Fr. "paraison," a passage	A preliminary shape or blank from which a glass article is to be formed
Paste mold	Method of preparation	A mold lined with adherent carbon, used wet for blown ware

Pig	Fancied resemblance	Iron rest for gathering-iron or punty
Potash	Original source, ashes from cooking fires	(1) K_2O, the oxide of potassium (2) loosely, raw material; *e. g.*, hydrated potassium carbonate
Punch tumbler	Hindu "panch" 5; punch having five original ingredients—arrack, tea, sugar, water, and lemon	A mouth-blown drinking glass
Punty	Fr. "pontil"	A gathering iron
Ream	Fr. "rame," bundle of paper	Inhomogeneous layers in rolled sheet glass
Ring hole	Location of gathering ring	An opening in the tank through which glass is gathered
Rock crystal	Originally colorless, transparent quartz	Highly polished blown ware, hand cut or engraved
Roller	Resemblance	A blown glass cylinder for flattening into window glass; almost obsolete
Salt water	Fluidity and saltiness	Same as glass gall
Scum	Dan. "skum"	Unmelted floating material, usually high in silica
Seed	Resemblance to plant seed	Very small bubble
Shadow wall	Obvious	A wall, usually silica brick, built on the division wall and cutting off flame and radiation from the working end of a tank
Shop	Work room	A team of workmen producing glassware
Silica	La. "silex," flint	SiO_2, silicon dioxide
Skew brick	Slanting or oblique	Brick with slanting face carrying edge of crown
Slag	Sw. "slagg"	Crude glass, as that formed by corrosion or fluxing of refractories or in metallurgical furnaces
Slip	Its condition	A clay-water mixture, deflocculated, easily poured for casting

Soda	Ital. "solido," a solid	(1) Na_2O, the oxide of sodium (2) Loosely, soda ash, sodium carbonate
Stria (Pl. Striae)	L., a furrow	Inhomogeneities like very fine threads, in optical glass
Striking	Suddenness	Change of color by reheating
Teaser	Fr. "tiseur," a stoker	A furnace tender
Throat	Anatomy	Narrow passage for glass from melting to working chamber (inside neck)
Tongue-tile	Resemblance	A projecting partition between gas and air streams
Tuck stone	Position and purpose	Refractory shape filling gap between side-wall and jamb wall
Tumbler	As. "tumbian," dance. Originally, drinking glasses were round-bottomed and must be emptied before setting down	A drinking glass
Tuyere	Fr. "tuyau," pipe	Pipe through which air is forced into the furnace or producer
Wave	Resemblance	A cord or surface marking on blown ware
Weathering	Natural conditions	Corrosive effect of moisture on glass

Greek Letters

Common Uses as Symbols in Glass Technology

English Spelling	Greek Capital Letters	Greek Small Letters
ALPHA	A	α—Coefficient of thermal expansion; natural or low-temperature crystal form
BETA	B	β—Specific heat constant; secondary or high-temperature crystal form; compressibility
GAMMA	Γ	γ—Surface tension; higher crystal form
DELTA	Δ	δ—Increment or differential; birefringence
EPSILON	E	ϵ—Unit elongation or strain; energy potential
ZETA	Z	ζ—Logarithm of viscosity; deformation at breaking point
ETA	H	η—Viscosity, poises; entropy
THETA	Θ	θ—Degrees of thermal shock; plane angle
IOTA	I	ι
KAPPA	K	κ—K Dielectric constant; κ conductivity
LAMBDA	Λ	λ—Wave length
MU	M	μ—Micron (10^{-4} cm.); $\mu\mu$ micro-micron (10^{-10} cm.); mμ milli-micron (10^{-7} cm.)
NU	N	ν—Dispersion
XI	Ξ	ξ
OMICRON	O	o
PI	Π	π—Circumference $\div$ diameter, 3.1416
RHO	P	ρ
SIGMA	Σ	σ—Σ Summation; σ Stefan-Boltzmann constant; interfacial surface tension; Poisson's ratio
TAU	T	τ
UPSILON	Υ	υ
PHI	Φ	ϕ—Fluidity, or $\frac{1}{\eta}$
CHI	X	χ
PSI	Ψ	ψ
OMEGA	Ω	ω—Ohms

Section XI

ADVERTISING INDEX—BUYERS' GUIDE

Advertising Index—Buyers' Guide

ACHESON COLLOIDS CORPORATION

Manufacturers of "dag" Colloidal Graphite

1728 Washington Ave., Port Huron, Michigan

PRODUCTS:

"Dag" colloidal graphite—Type 1104, as manufactured and sold by Acheson Colloids Corporation is available in the concentrated form containing 10% stabilized graphite.

"Aquadag" is the trade-mark of Acheson Colloids Corporation's dispersion of colloidal graphite in distilled water. The product has a 22% solids content and is designed for dilution prior to use.

The concentrated forms of the oil and water dispersions may be diluted with other liquids that are miscible and free of electrolytes. Colloidal graphite is also available in castor oil and glycerine carriers.

Kerosine dispersion—1804, containing 10% stabilized graphite.

Carbon tetrachloride dispersion—Type 3004, containing 10% stabilized graphite.

APPLICATIONS:

CONVEYOR PARTS

The type of fluid carrier recommended for high temperature applications varies with the problem at hand. Wherever it is important that a non-inflammable fluid be employed, dispersions of colloidal graphite in carbon tetrachloride are useful. Whenever volatile petroleum fluids are better adapted to conditions, colloidal graphite dispersed in kerosine, mineral spirits, spindle oil, or other liquids may be employed. Colloidal graphite can be dispersed in the more viscous of petroleum fluids providing they are satisfactory.

Advantages gained by using "dag" colloidal graphite dispersed in low viscosity or volatile fluids are: (a) durable lubrication due to the self-lubricating graphoid surface formed on friction parts; (b) protection of remote parts because of the penetrating qualities of the minute graphite particles; (c) reduced carbon, flake off, resin and gum because of the lighter fluids employed.

GLASS BOTTLE MACHINES

Colloidal graphite can be used successfully in treating the iron molds that form glass bottles on automatic machines. Briefly, a lubricating veneer of graphite is formed on metal parts to prevent the sticking of bottles and so reduce scrap and improve production.

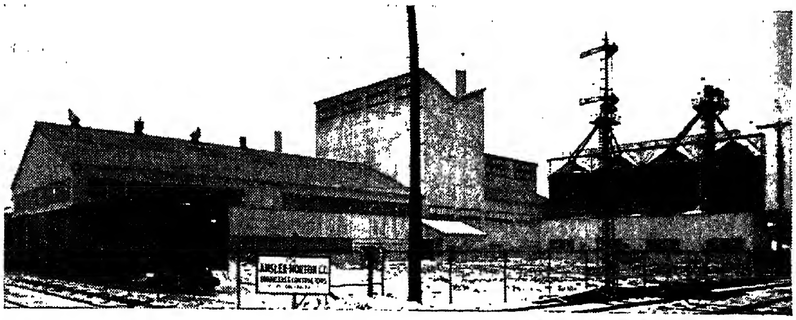
"Dag" colloidal graphite—Type 1104 has been used effectively on the "Lynch" Bottle Blowing Machine, the "Owens," "O'Neill," and other types. In this connection one concern reports that the application of colloidal graphite to the parison molds "provides a graphoid skin on surfaces that aids considerably the flow of glass. At a later blowing stage, by reason of this film, the glass is prevented from coming in contact with the molds, thus reducing the tendency to drag when they are opened to deliver the finished bottle."

Graphited oils have been found useful for the lubrication of moving parts in such machines as are exposed to high temperatures. In one test of 910 hours on two bearings having a temperature on the outside housing of 170°C., this type lubricant gave remarkable results. In this, and similar applications, the efficiency of the colloidal graphite makes possible its use in small quantities, thus tending to eliminate the formation of carbon deposits that may occur when plain lubricants are employed.

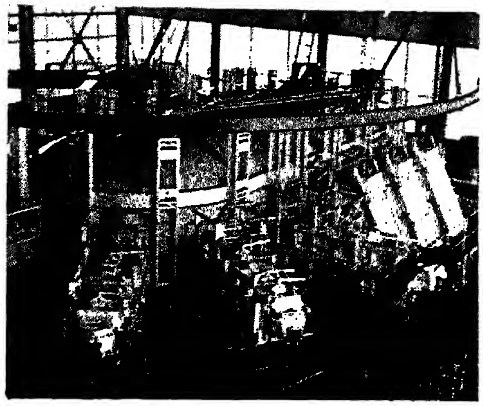
GLASS-DRAWING OR ROLLING MACHINES

The prevailing temperatures in "Brevet Fourcault" glass-drawing machines are estimated at 400° to 430°C., values which make lubrication impossible with most oils. To overcome this difficulty the journals are treated with "1104" at the time of assembling the machine. Afterward, during operation, it is lubricated with a light oil containing a lower concentration of graphite.

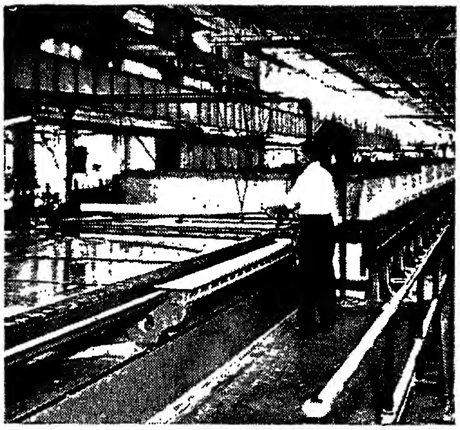
With such lubrication it has proved possible to allow the machines to run for four months without overhaul. Previous to the use of colloidal graphite this had to be effected every three to four weeks. It is interesting to note that overhauls now consist only of cleaning any carbon deposit out of the oil grooves instead of a complete overhaul and refinishing of the bearings. Furthermore, the entire machine runs more silently and the amount of electric current used is less than before.



factories and equipment

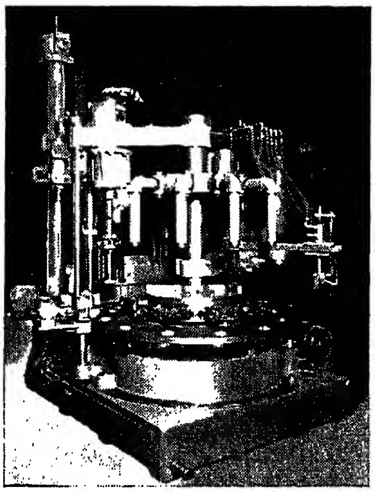


Glass Tank Furnaces



Sheet Glass Lehrs

Gas Producers—Coal Handling Machinery



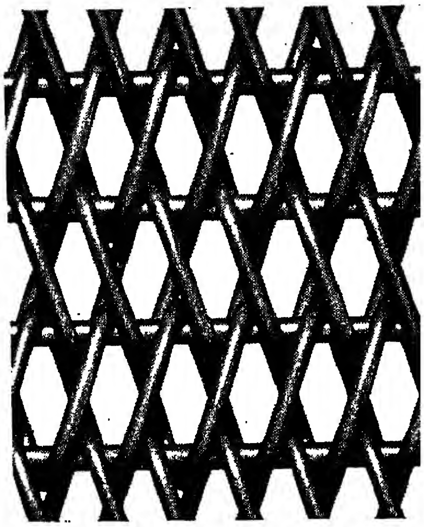
Heavy Duty Presses

Container Lehrs

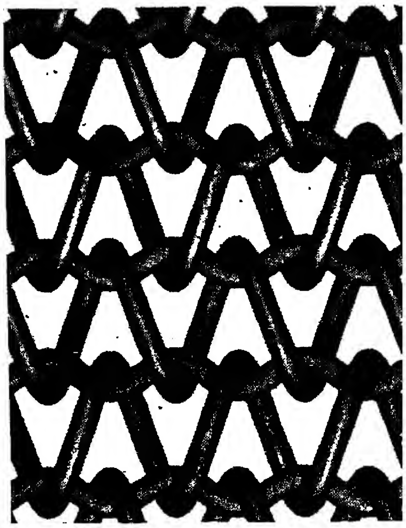
GLASS MELTING FURNACES

The AMSLER-MORTON COMPANY

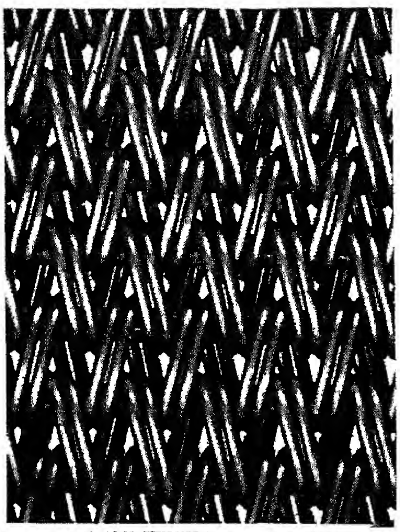
FULTON BUILDING • PITTSBURGH, PA.



UNIVERSAL WEAVE



BALANCED WEAVE



MULTIWIRE WEAVE

AUDUBON Metalwove LEHR BELTS

for Annealing and Decorating Up to 1350°F.

Audubon Metalwove Lehr Belts are made in various alloys to give maximum life, minimum maintenance and to prevent marking of the ware. They are now successfully used for annealing Glass Blocks, Tumblers, Bottles, Stem Ware, Blown and Pressed Ware, Light Globes, and for decorating work at higher temperatures to burn in the color. . . . The complete Audubon line of lehr belts includes Single Weave, Universal, Balanced, Improved Balanced, Multiwire and Interwoven Types. . . . Our engineers will gladly give you the benefit of their experience. Address the nearest office listed below for our 44 page Catalog No. 50.

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WIRE CLOTH CORP.

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Pittsburgh	Minneapolis
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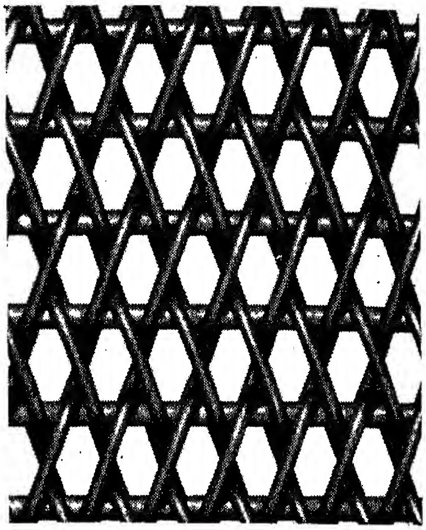
	San Francisco



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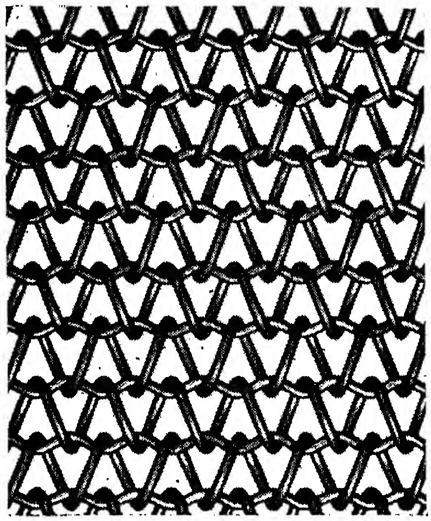
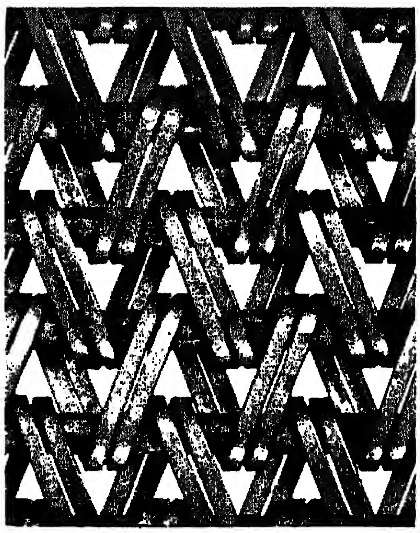


BALANCED WEAVE



MULTIWIRE WEAVE

MIN-OX MOULDS

are the result of seventeen years of research, development and specialization in the production of alloys for glass mould use. Min-ox alloys may be divided into two main groups; one—non-ferrous alloys classed as complex yellow brasses, the other group—ferrous alloys are highly alloyed irons.

In the development of Min-ox alloys for glass moulds there has been the closest correlation of metallurgical laboratory results and actual operating results in the glass factory. Through this system improvements have constantly been made in Min-ox alloys over the years—improvements not only in the complicated analyses, but also in the technique of producing them and in the establishment of scientific control of the varied operations. Min-ox alloys have been made possible only through this special fabricating technique.

Some of the factors which have contributed to make Min-ox the outstanding mould alloys are: absolute accuracy in weighing the component elements necessary for their production, the melting of these alloys in special furnaces which insure maximum control of temperature, atmospheric conditions and fuel used. These special furnaces in which a great deal of time and money has been invested are as much a Binney development as Min-ox itself.

As for the many elements which are used in the production of Min-ox alloys space does not permit a detailed discussion of these. However, it is important to note that our alloys contain certain of the so-called rare elements whose properties are essential in obtaining the highest degree of heat resistance. Years of experience have proven that even the best grade of pig iron and ingot brasses cannot produce the desired results, hence the inherent qualities of Min-ox are derived from the use of many elements seldom found in any of the heat resisting metals for glass moulds.

In actual performance Min-ox alloys resist the formation of oxide or any adhering scale which would be present with ordinary metals and which unless cleaned off would result in marked and dull glass. Also where scale exists fine fidelity of design is seriously impaired. Proper heat conductivity is another attribute of Min-ox alloys and due recognition has been given to the problem of the rapid cooling of parts that overheat and the retention of heat for parts that tend to cool rapidly.

Min-ox moulds will help cut production costs through their ability to resist scale, reducing to a minimum cleaning and costly production interruption and the practical elimination of fire finishing. Further advantages are obtained in product improvement. Glassware made from Min-ox moulds has a superior finish, is of sparkling brilliance and cameo-like clearness of intricate design. These product improvements resulting in increased sales plus production savings more than offset the slightly higher cost of Min-ox alloys over ordinary mould metals.

Min-ox produces better glass at lower costs.

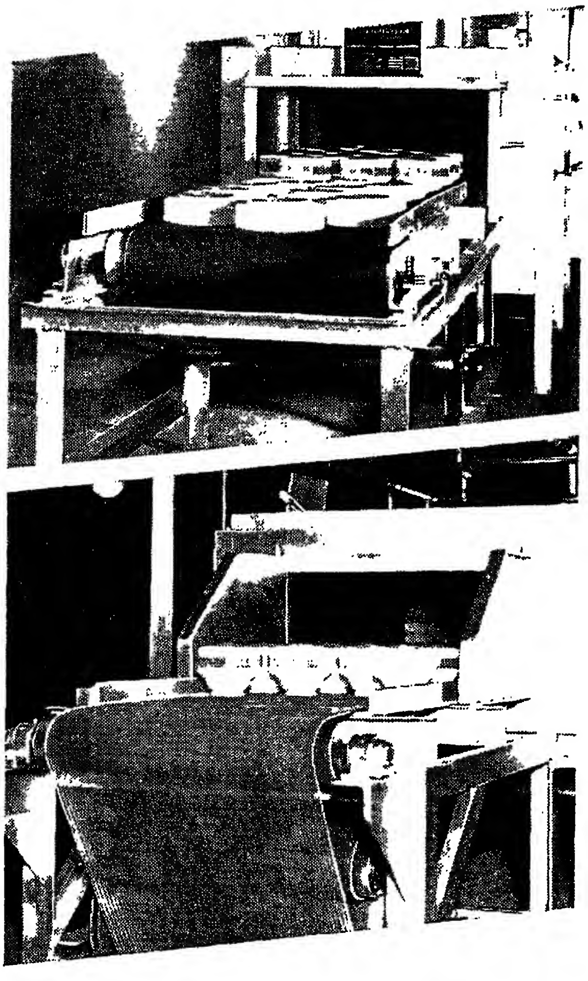
THE BINNEY CASTINGS COMPANY

TOLEDO, OHIO

originators of alloys for glass molds

CAMBRIDGE Balanced Belts

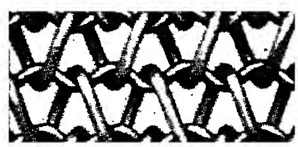
Up Your Operating Efficiency



THEY assure more efficient lehr operation. Scientifically developed, they are perfectly adapted for annealing all types of hollow ware. Their special balanced construction is your guarantee of uniform, higher quality products. This construction—alternating spirals connected with crimped wires—eliminates side creep, provides flat carrying surface, makes these belts so flexible that they pass over any diameter of pulley or driving drum, yet they are tremendously strong.

This balanced construction is obtainable in any specifications to suit your individual requirements. Write us today for further information or assistance. Our engineers, located strategically throughout the country, are quickly available to you to assist in planning your lehr belt installation.

(Above) Photograph shows the charging end of a Surface Combustion Corporation Lehr in which Cambridge Balanced Belting has been used. (Below) Photograph showing the discharging end of this same new installation.



Close-up view of Balanced Mesh Belt showing the alternate spiral construction and crimped wire connection.

CAMBRIDGE WIRE CLOTH CO.
CAMBRIDGE, MARYLAND

Boston - New York - Baltimore - Pittsburgh - Detroit - Chicago - San Francisco - New Orleans

PLE

ENGINEERS AND CONTRACTORS

400 East Beau St. WASHINGTON, PENNA., U.S.A. Cable Address: "Simplex"

Simplex Products and Services

- Glass Melting Tanks and Furnaces
- Glass Bending Ovens
- Silk Screen Decorating Machines
- Luminous Ports for Tanks
- Annealing and Decorating Lehrs
- Interlocking Suspended Arches
- Circular Arches
- Batch Systems
- Fuel Oil Systems
- Controls
- Stokers
- Cullet Washing Plants
- Incinerators
- Vacuum Dryers
- Evaporators
- Conveying Equipment
- Water Softening Plants
- Silicate of Soda Plants
- Producer Gas Plants
- Soot Disposal Systems—Industrial and Domestic
- Complete Glass Manufacturing Plants
- Ultra Modern Ventilated Steel Factory Buildings
- Designs
- Appraisals
- Glass Manufacturing Equipment

Call in a Simplex Engineer for consultation without obligation.

Typical Frazier-Simplex Brick and Steel Factory Building

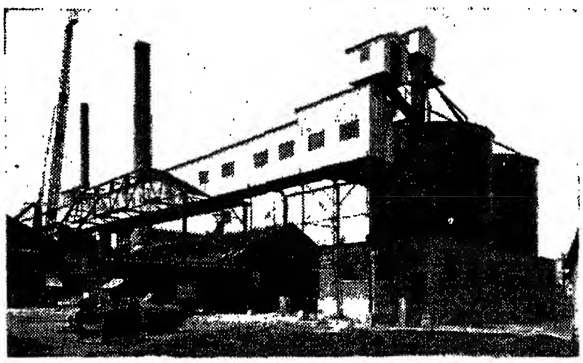
Producer Gas Plants

Designed to very greatly minimize burning out periods and also to give constant supply of good quality gas. In conjunction with these Producer Gas Plants, the Simplex Soot Disposal System enables any manufacturer to operate within the city limits where his factory may be located without the nuisance of polluting the atmosphere with carbon dust or soot.

Batch Systems

Simplex designed Batch Plants minimize the necessary labor element and give more accurate weighings and mixings. Continuous Belt Conveyor Types and Mono-Rail Hopper designs are available.

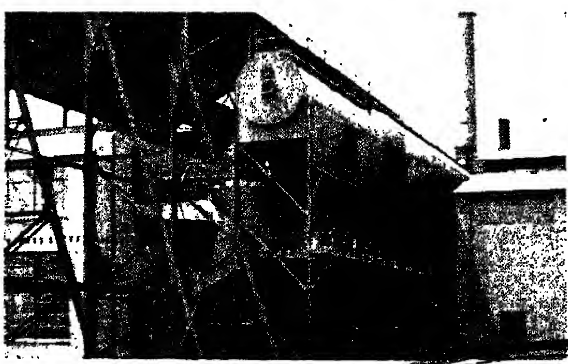
Power shovel unloading equipment and hopper vacuum unloading equipment are also supplied.



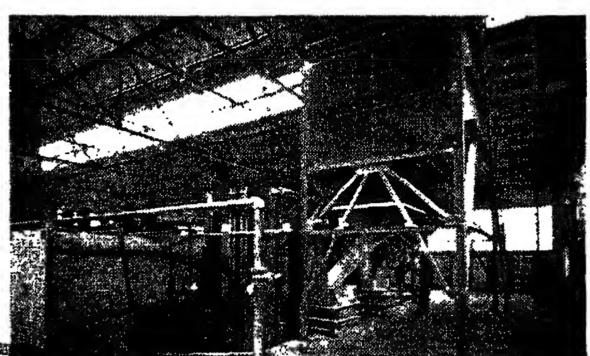
Batch Plant Container Manufacturing

Cullet Washing Systems and Dryers can be built in conjunction with these Batch Plants. The design lessens to a great extent the hazards to workmen of communicable diseases, such as silicosis and pneumoconiosis.

Glass Melting Tanks and Furnaces



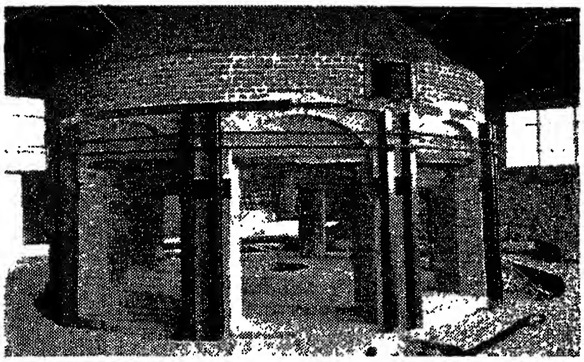
Modern Producer Gas Piping for Plate Glass Plant



Producer Gas Fired Regenerative Continuous Tank.

FRAZIER-SIMPLEX, INC.

Recuperative or regenerative types can be fired crosswise or endwise of the tank with any type of fuel such as oil, natural gas, producer gas and propane. Unusually low fuel consumption per square foot of hearth area. These tanks or furnaces are suitable for manufacturing glass for bottles, tableware, sheet or plate glass, glass blocks, lead tubing, etc.



Typical Simplex Recuperative Pot Furnace.

Annealing Lehrs

Complete-muffle, semi-muffle, or open fired variety. Electric Heat can also be used. These lehrs will successfully anneal any type of glass.

Decorating Lehrs

Either Fuel Fired or Electric Fired designs, or combinations of the two; afford remarkable fuel economy together with excellent atmosphere firing control.

Mezzanine Floor and Ready Heat Unit Lehrs, Table Ware Plant.

More than fifty installations of the new Simplex Ready Heat Unit Lehrs have already been made in the glass industry.

Arches

For bringing the products of combustion closer to the melt and saving fuel in glass manufacturing, the Interlocking Suspended Arch is unexcelled. The troubles experienced with tie rods for taking up contraction or letting out for expansion when cooling or heating the tank is entirely eliminated by this unique crown construction.

The Interlocking Suspended Arch.

This Interlocking Suspended Type of Arch can be used as an Adjustable Shadow Wall for all tanks, especially sheet and plate glass tanks, with excellent refining end temperature control.

Other uses for the Arches are Crowns for Checkers for Open Hearths, Blooming Mills, Strip Mills, Tunnel Kilns, Enameling Ovens, etc.

The Simplex specially designed Circular Sprung type Arch has advantages of shorter time for installation and a more substantial construction. Catalog containing interesting arch details sent free, on request.

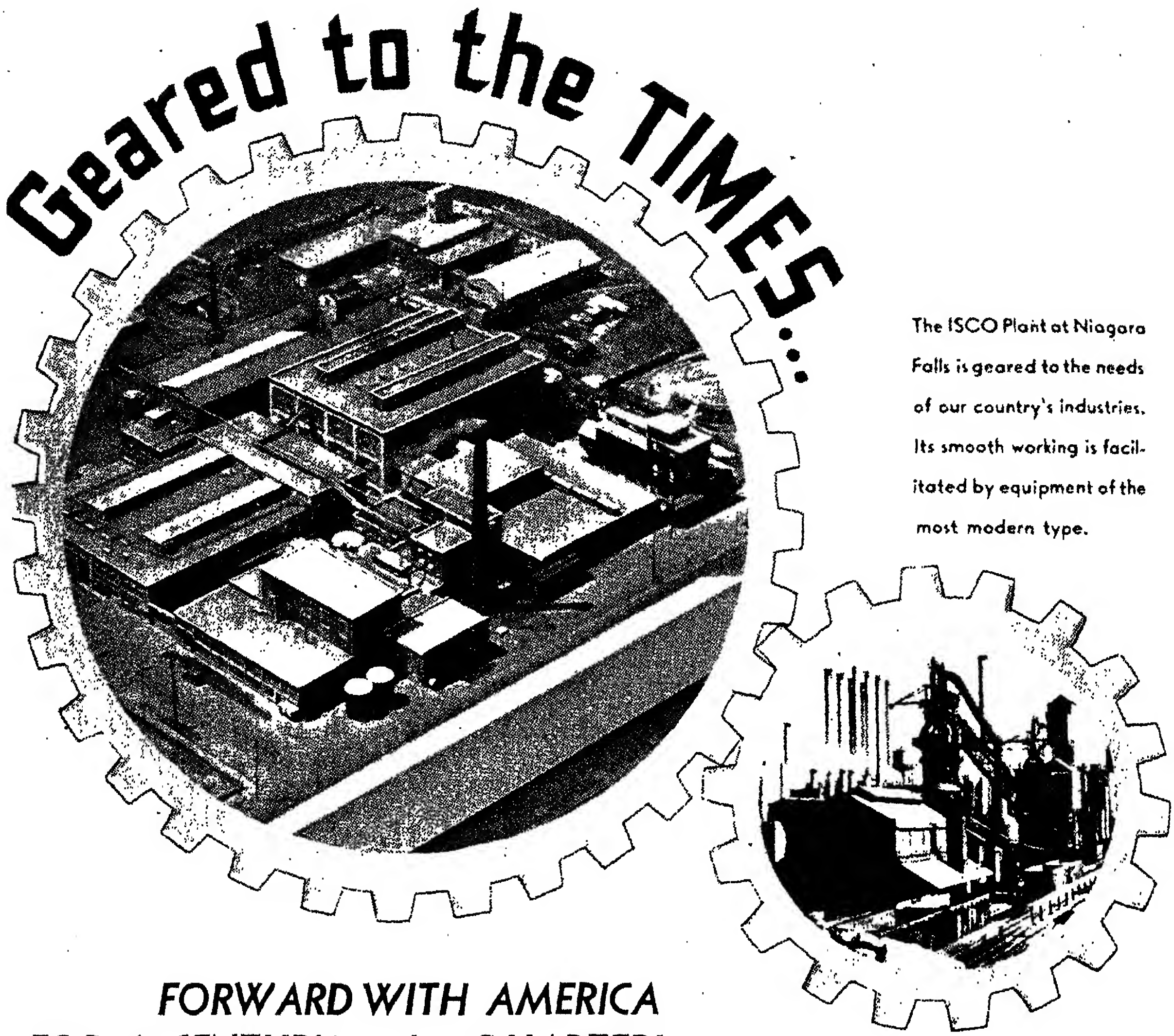
Interlocking Suspended Backwall and Covered Dog House

Six years of successful operation are now behind this design. It has eliminated a large percentage of dusting at the tank charging end and prolonged life and efficiency of checkers, also refractories in the upper structure. This design gives greater flame coverage which produces more efficient melting. It is flash melting, the greatest development in years.

Suspended Backwall for Fiberglass Plant.

Dryers

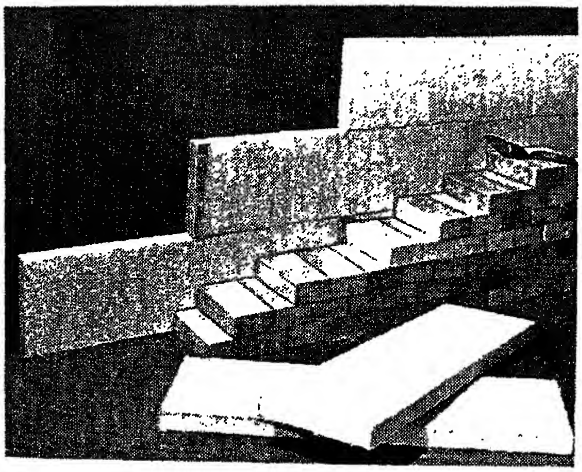
Completely muffled Dryers for one or more color decorations are available.


Geared to the TIMES...

JOHNS-MANVILLE

22 East 40th St., New York

Johns-Manville Insulating Materials for Glass Making Equipment



J-M Superex Block and Pipe Insulation

Superex is the most generally adaptable insulation for temperatures up to 1900°F. Made of specially selected and calcined diatomaceous silica, blended and bonded with asbestos fibre, it combines the essential qualities of high heat-resistance and exceptional insulating value. The large size sheets in which it is furnished not only cut down installation costs, but also reduce the number of joints, thus minimizing heat losses.

Superex has a low thermal conductivity, will safely withstand temperatures up to 1900°F. with negligible shrinkage, and, although relatively light in weight, possesses ample strength for all purposes for which it is recommended.

Superex Insulation is furnished in flat or curved blocks and in sectional and segmental pipe insulation. Blocks are 3″x18″, 6″x36″ and 12″x36″, flat or curved, in thicknesses of 1″ to 4″. Minimum thickness of curved blocks, 1¼″; of 12″-wide flat blocks, 1½″. Other sizes on special order. Weight about 2 lb. per sq. ft. 1″ thick. Pipe insulation furnished in 3-ft. sections or segments, 1″ to 3″ thick.

Superex Blocks are widely used in the Glass Industry for insulation of regenerators, flues and uptakes; melting tanks; flattening ovens; lehrs; pot arches and producer gas mains; and, in the power plant, for boiler walls and high temperature pipe lines.

J-M 85% Magnesia Block and Pipe Insulation

J-M 85% Magnesia has, for many years, been the most widely used insulation for boilers, furnaces, lehrs, steam lines, etc., where temperatures to which it is subjected do not exceed 600°F. Today, it still remains the No. 1 choice for long life, freedom from maintenance, and continued high efficiency in service.

J-M Insulating and Insulating-Refractory Brick

For purposes where insulation in brick form is indicated, Johns-Manville has a complete line of insulating brick, as well as combination insulating-refractories. The use of the latter materials is rapidly increasing, since these insulating-refractories cut down heat storage capacity, reduce weight and usually result in considerably lower construction costs due to the thinner walls made possible.

Other Johns-Manville Products

Johns-Manville also offers many other types of insulating blocks and pipe covering, insulating-refractory concrete, a complete line of insulating cements and fillers, as well as roofing and siding, refractory products, packings, electrical conduit, vent pipe and stacks, and many other products of service to industry. The complete catalog of J-M Industrial Products, Form GI-6A, is free on request.

THE MULLITE REFRACTORIES CO., SHELTON, CONN., U.S.A.

"Pioneers in Mullite Super-refractories"

"Shamva" Products

TRADE MARK REG. U. S. PAT. OFF

World's Foremost Mullite Super-refractories

BRICKS — SHAPES — CEMENTS

In "Shamva" mullite super-refractories, the unique advantages of mullite have been developed to the highest degree, resulting in refractory products of surpassing performance in the mullite-sillimanite field.

To the severe service requirements of the Glass Industry, "Shamva" mullite brings the following advantages:

1. High Softening Point, closely approaching its melting point of 3335°F (p.c. equivalent 38).
2. Low Coefficient of Expansion and Contraction—.0000045 per degree Centigrade. At 3200°F "Shamva" mullite shows 0.0% permanent linear shrinkage.
3. Indifference to Thermal Shock. In 10 cycles of A.S.T.M. spalling test our product shows absolutely no spalling. Tests of 73 cycles produce no mechanical defects.
4. Imperviousness to Slag Erosion. Extreme resistance to slag makes "Shamva" Mullite especially applicable for dog houses, throats, tuckstones, etc.
5. Negligible Tendency to Vitrify.
6. Ample Load-bearing Capacity. With its interlocking crystalline structure, "Shamva" Mullite shows no deformation under A.S.T.M. 50 lbs. sq. in. test at 2650°F, and less than 2% at 3000°F.
7. Chemical Neutrality. Following is a typical analysis of "Shamva" Mullite:

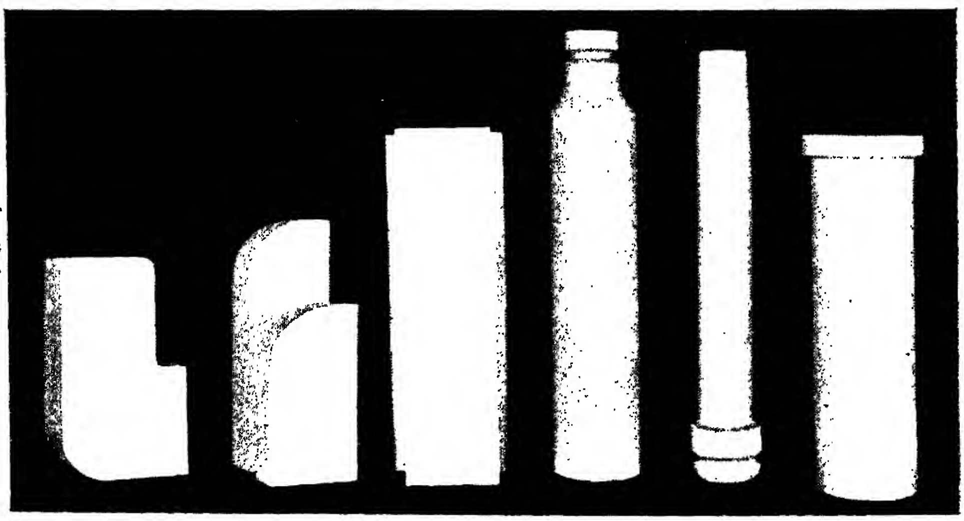
Al_2O_3	66.10
SiO_2	32.13
Fe_2O_3	.20
TiO_2	.75
CaO	.08
MgO	.08
Na_2O	.34

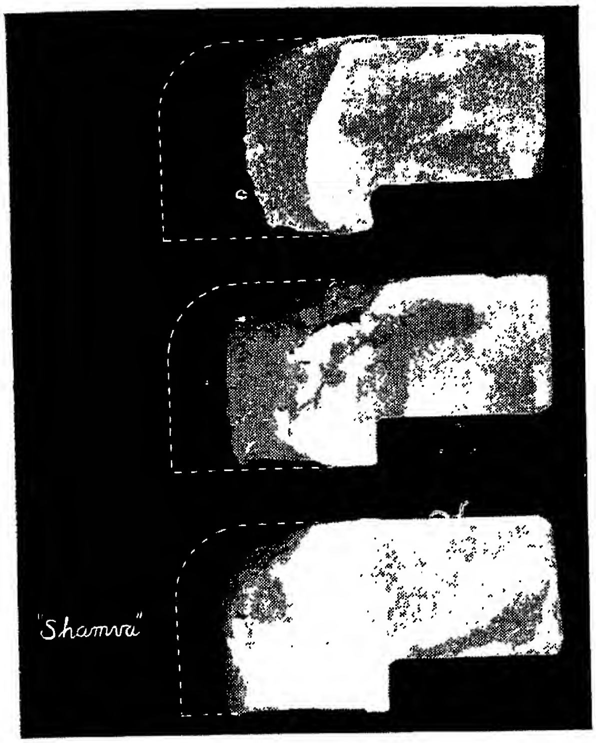
* The negligible iron content is an important factor in the superior physical properties of "Shamva" products.

USES IN GLASS TANKS

Due to its exceptional refractoriness and rigidity under heavy loads at high temperatures, and under severe conditions of

Various types of "Shamva" Mullite tuckstones, feeder tubes and

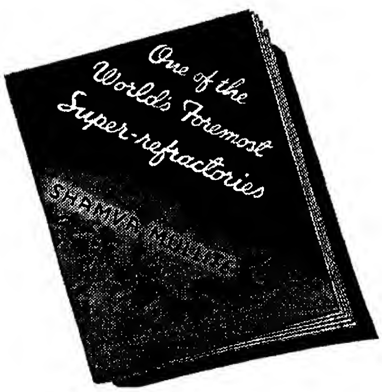




The above tuckstones were used side by side in a glass tank for many months. "Shamva" Mullite superiority is clearly demonstrated. The two top tuckstones were of competing manufacture nearest in analysis to "Shamva" Mullite.

slag erosion and thermal shock, "Shamva" Mullite adds materially to the working life of glass tank furnaces when used for

- Port Cover Tile
- Port Floor
- Burner Blocks
- Tuckstones
- Invert Arches
- Port Arch
- Tongue Arch
- Center Division Port Walls
- Port Necks & Uptakes
- Port Snouts
- Port Jambs
- Mantel Block
- Mantel Arch
- Breast Walls
- Rear Wall
- Pyrometer Blocks
- Peep Hole Blocks
- Bridge Wall Cover Blocks
- Feeder Channel Blocks
- Shadow Wall
- Feeder Parts
- Flue & End Walls
- Patching
- Flux Blocks
- Charge Hole & Flux Supporting Blocks
- Pot Furnaces



40-page Mullite Handbook Free upon Request, showing detailed 2-color diagrams of glass tank applications, also useful performance data.

and in Ceramic Kilns for

Batts Saggers Posts Slabs Enameling Muffles Car Tops, etc.

CEMENTS

A complete line of "Shamva" Mullite cements is produced, including SM-40 Mortar Cement, SM-50 Dry Patching Cement, SM-60 Plastic Patching Cement, SM-70 Ramming Cement.

SILICON CARBIDE

We manufacture a full line of silicon carbide shapes and bricks, including kiln furniture, car tops, Lehr tile and many other items.

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Carrick 0910

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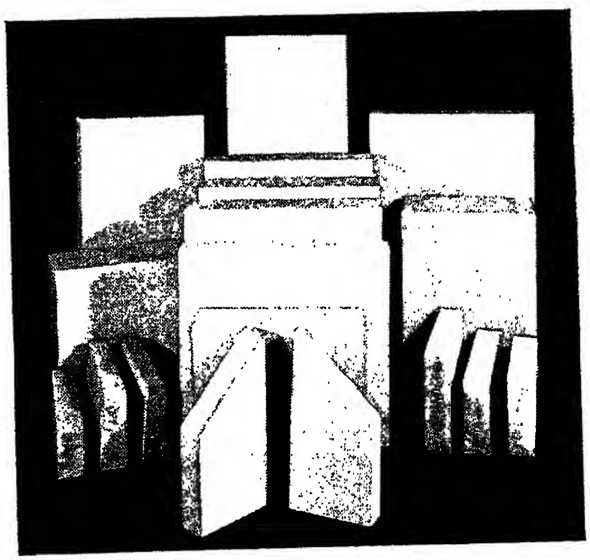
Elizabeth 3-2316

DETROIT, MICH.
G. T. Hubbell
612 Stephenson Bldg.
Trinity 1-1160

KENMORE, N. Y.
H. L. Anderson
199 Stillwell Ave.
Delaware 4036

PHILADELPHIA, PA.
R. E. Farmer
1120 N. 65th St.
Trinity 5886



A few examples of the wide variety of "Shamva" Mullite refractory shapes for glass tank superstructure.

THE MATHIESON ALKALI WORKS, (INC.)

Manufacturers of Chemicals

60 East 42nd Street, New York, N. Y.

Works

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Washington, D. C., 1625 Eckington Place, N. E.

Products

Soda Ash—Caustic Soda—Bicarbonate of Soda—Liquid Chlorine—Bleaching Powder—H T H Products—Ammonia, Anhydrous and Aqua—Fused Alkali Products—Synthetic Salt Cake—Dry Ice—Carbonic Gas—Analytical Sodium Chlorite.

(Left)

Loading Dense Soda Ash into a freight car at Mathieson's Saltville, Va. plant.

Mathieson Dense Soda Ash

Produced solely for the glass industry, Mathieson Dense Soda Ash meets the exacting standards of modern glass making. It is exceptionally free from dust, over-sized particles and impurities or foreign matter that might affect the quality of the batch. Its uniform granular character helps in securing quick, efficient melting and assists in producing more uniform batches.

Mathieson Dense 58% Soda Ash is shipped in 400-lb barrels, 300-, 250-, 200-, 150-, and 100-lb. bags and in bulk.

Points of manufacture are Saltville, Virginia, and Lake Charles, Louisiana.

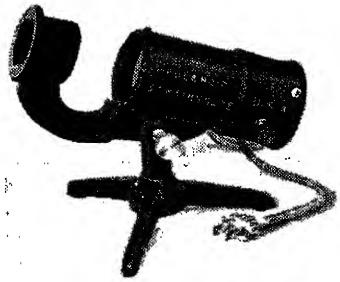
GLASS STRAIN TESTING POLARISCOPE WITH POLAROID POLARIZERS

meets every need in polariscopes

No matter what your need in strain testing may be, the Polarizing Instrument Co. offers an instrument to fit your particular requirements.

BINOCULAR TYPE—for large field work. Brilliant strain patterns—adjustable—binocular viewing—precise.

SPECTACLE TYPE—Mounted in unit with sensitive tint plate of 565 millimicrons presents a uniform field of large aperture. Standard size apertures 6″ and 12″ diameter but any special requirements can be met.



THE PORTABLE—Less than 2 lbs. Offers same high precision obtained in larger strain testing units. Works on 110 volts a.c. or d.c. Particularly useful to sales executives, service men, laboratory work and branch offices.

If your problem is Strain Detection we can help you through standard equipment or special adaptations.

THE POLARIZING INSTRUMENT COMPANY

630 FIFTH AVENUE (Rockefeller Center), NEW YORK CITY